How to use this manual

This manual comprises sub-documents that are relevant to your system. They have been designed to guide you through the operation of the system logically and simply. Each of these sub-documents describes one of the component parts of the system or explains what to do with it before you proceed to the next operation. They all have a reference filename which you do not normally need to use. The filename helps us to trace the different sub-documents so that we could generate another copy of the manual for your system if this one is lost or damaged

Each of the main sections in the manual is separated from the others by a divider card. Use the main table of contents at the beginning of the manual and then use the table in the relevant section to find the information you need.

Diagrams that are referred to from more than one place in the manual (and other useful drawings) are in a separate section. Some of these diagrams are folded so that you can pull them out and see them while reading the text which refers to them.

Additional manuals may be provided with your system to describe the details of some of the component parts. In particular, most electronic equipment is supplied complete with a manual, and you may need to refer to these separate documents to find out how to carry out some of the operations if you are not familiar with the equipment.

Safety

Warning **It is your responsibility to ensure your own safety, and the safety of the people working around you.**

Cryogenic fluids and high magnetic fields are potentially hazardous, and you must take precautions to ensure your own safety. The *Oxford Instruments* booklet "*Safety Matters*" has been included in this manual. It contains essential information and detailed recommendations about the precautions that you should take. Any additional information that applies specifically to your system is provided separately in the 'Safety' section of this manual.

Warnings

Please read this manual before assembling or commissioning the system. If you do not follow the correct procedures you might be injured or you might damage the system beyond repair. Oxford Instruments cannot accept responsibility for damage to the system caused by failure to observe the correct procedures laid down in this manual.

Other manuals supplied with the system

The following documents (marked ✓) are also supplied with the system.

Elementary Practical Cryogenics	✓
Introduction to thermometry below 1K	
GF3 pumps	
VC series gas flow controllers	
ILM200 family of cryogen level meters	✓
ITC501 temperature monitor	
ITC502 temperature controller	
ITC503 temperature controller	
PS180-20 superconducting magnet power supply	✓
PS120-3 superconducting magnet power supply	
ISS10 superconducting shim power supply	
GPV24 interface	
Dilution refrigerator temperature controller, 3142	
AC resistance bridge (Mk III)	
SMC4 stepper motor controller	
Auto needle valve and Auto GFS for ITC502 and ITC503	
Data sheet for a calibrated thermometer	
RhFe reference scale 1.5 to 800K, for 3 point calibrated sensors (1985 revised to ITS-90)	
2000 ohm ruthenium oxide resistance thermometer. Generic calibration	
Nuclear orientation thermometry using the PCA-P multichannel analyser	
AVS-47 AC resistance bridge	
TS-530 temperature controller	
Manostat instruction manual	
HVP1 pumping system	
ObjectBench system control software	
Teslatron system control software for Kelvinox^{IGH}	
Teslatron lambda controller	
Teslatron system control software	
DC-SQUID	
PHI-O RF-SQUID	
Manuals for vacuum pumps	
Manuals for vacuum accessories	

Contents of the Introduction section

The following documents describe the system and give some information about the principle of operation. If you are experienced you may not need to read the Introduction in detail but you must read the warnings contained in it.

Superconducting solenoids

The world's first commercial superconducting magnet was produced *by Oxford Instruments*, and now, more than 25 years later the company still leads the world, with fields higher than 20 T available. This technology allows customers to produce extremely high magnetic fields in laboratory scale cryostats without the kW to MW power supplies needed for non-superconducting magnets. In most cases the cost of refrigeration for a superconducting system is much less than the cost of the power required to run an equivalent non-superconducting system.

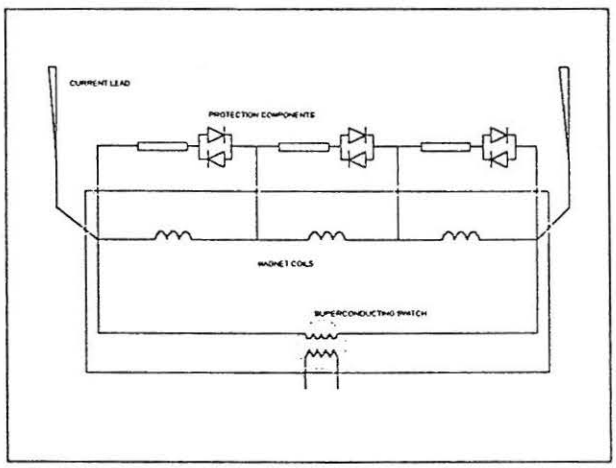
The magnet consists of a number of coaxial solenoid sections wound using multi-filamentary superconducting wire. The magnet is constructed using the Magnabond system, an integration of proprietary techniques, developed by *Oxford Instruments*. It gives a structure which is both physically and thermally stable under the large Lorentz forces generated during operation.

Additional coils may be fitted to the basic windings to modify the shape of the field. 'Compensation coils' are often used to improve the homogeneity at the centre of field by reducing the rate at which the field drops at the ends of the coils (due to finite winding length effects). They are usually wired in series with the main coils so that they are energised with the magnet. 'Shim coils' (or shims) are used to remove residual field gradients; they may be wired in series with the main coils to give a basic level of correction or independently to give finer adjustment. Shims may be either cold superconducting coils or room temperature 'normal' coils. 'Cancellation coils' are often fitted to one end (or sometimes both ends) of a magnet to give a low field region quite close to the centre of field; for example < 10 mT (or 100 gauss) may be achieved over a region only 30 cm away from the centre of field of a 15 T magnet.

Persistent mode operation using the superconducting switch

One of the main advantages of the superconducting magnet is the ability to put it into the 'persistent mode'. In this type of operation, the superconducting circuit is closed to form a continuous loop, and the power supply can then be switched off, leaving the magnet 'at field'. The field decays only very slowly, at a rate depending on the inductance, the design and number of superconducting joints and the choice of conductor. A decay rate of 1 part in 10^4 relative per hour is easily achieved in a typical magnet, but this can be improved to 1 in 10^7 relative per hour for specific applications (for example, high resolution NMR spectroscopy). Persistent mode operation is achieved using a superconducting switch which is fitted to the magnet in parallel with the main windings. The diagram on page 2 shows a typical simple circuit.

When the magnet is to be energised, the switch is held open, (that is 'normal' or non-superconducting), by the application of heat from the switch heater. In this state, although the resistance of the switch is typically only a few ohms, it is so much higher that that of the magnet that almost all of the current flows through the magnet. Soon after the magnet reaches the desired field the induced voltage across the switch drops to zero and all of the current then flows through the magnet. The switch is closed by turning off the heater, (to allow it to return to the superconducting state). After a few tens of seconds the current in the magnet leads is slowly reduced by 'running down' the power supply. (This process is referred to as 'running down the leads'.) As the current in the leads drops, the current flowing through the switch gradually rises, until it carries the full current of the magnet.



Simple magnet protection circuit, showing the magnet windings and superconducting switch.

Quenches

The magnet will only function properly providing that all of the conductors remain in the superconducting state. If any part of the windings goes 'normal' or resistive, the current passing through it will cause ohmic heating (I^2R); in turn this heating increases the size of the normal zone. Once the process has started, it is possible to stop it only if the disturbance is very small. Otherwise, the normal zone propagates rapidly through the whole of the coil, and may spread into other parts of the magnet. All of the stored energy in the magnet is dissipated rapidly, causing the liquid helium to boil off very quickly and often warming the magnet to a temperature significantly above 4.2 K. This type of failure of the magnet is called a 'quench'.

The stability of the magnet is strongly influenced by the design of both the conductor and the windings. Only a very small amount of energy is required to start a quench, and this releases a very large amount of stored energy. Even microscopic movements of the wires in the coils may be sufficient to quench the magnet.

After a magnet has quenched it will often be found that the quench has helped the windings to settle, and normal operation can continue after refilling the cryostat with liquid helium. Indeed in a brand new magnet several quenches may be experienced before the magnet reaches its design field, and the quenches occur at progressively higher fields. This procedure is known as 'training', and it is quite normal. The training is carried out in the factory, and the magnet is always given a thermal cycle to room temperature before it is re-energised, to ensure that it will not quench again. It is unusual for the magnet to quench after it has left the factory, and you may run a superconducting magnet system for years without seeing a quench. However, if a new magnet quenches on its first run after transport (as occasionally happens) this should not be a great cause for concern, because it is possible that vibration has disturbed the magnet slightly. One or two training quenches should be sufficient to restore the magnet to its full specification.

Magnet support systems

Magnet support systems are used to provide mechanical support for a superconducting magnet and its current leads, protection circuit, and other accessories. There are various services for the main helium reservoir on the top plate.

The helium transfer tube (or siphon) entry port is used to transfer cryogens into or out of the liquid helium reservoir. During precooling the 'blow out tube' is inserted into this port. Below the port there is a 'siphon cone'. This is connected to the upper end of a tube which goes to the bottom of the helium reservoir. Plug the transfer tube or blow out tube into this cone if you want to transfer liquid to the bottom of the reservoir or blow out all of the liquid. This is particularly important when the liquid nitrogen is blown out at the end of the pre-cooling process and when liquid helium is transferred into the system to cool it to 4.2 K.

Warning All the service ports should be sealed when the system is cold, to prevent air from entering the system. If they are not being used fit the plugs that we have provided.

Magnet current leads

The magnet current leads are optimised to carry the maximum operating current of the magnet and introduce as little heat as possible to the liquid helium. In some systems the current leads are demountable. These can be removed to minimise the liquid helium boil-off while the magnet is in persistent mode, (but only at the expense of higher helium consumption while the current is sweeping).

Magnet protection circuit

The magnet protection circuit is used in the event of a quench:

- to dissipate the energy stored in the magnet
- to make sure that high voltages are not produced.

Protection resistors (and diodes if appropriate) are provided for all magnet sections. The resistors are mounted on baffles attached to the magnet support structure or just above the magnet in the helium reservoir. They are wired to the magnet through an electrical connector. The connector also incorporates the wiring for the superconducting switch heater, making it impossible to run the magnet accidentally without the protection circuit attached (if a switch is fitted).

If diodes are used in the protection circuit then, under normal operating conditions, all the current passes through the magnet and ensures that the energisation current is proportional to the magnetic field. They also reduce heat load from ohmic heating in the protection resistors and hence reduce system boil off while the magnet is sweeping. If the magnet quenches, the barrier voltage is exceeded and the protection comes into operation automatically.

Liquid nitrogen shielded dewars (SMD series)

Oxford Instruments SMD series liquid helium dewars are available in two forms; liquid nitrogen shielded and vapour shielded. There are advantages and disadvantages to each type. The dewar supplied with your system is liquid nitrogen shielded.

This means that there is a liquid nitrogen reservoir which cools a radiation shield surrounding the liquid helium reservoir. It is also linked to the neck of the helium reservoir to reduce the amount of heat conducted into the liquid helium. This can be especially useful if the neck has to be very short.

The advantages of liquid nitrogen shielded dewars include the following features:

- relatively short dewars can be built with an acceptably low boil off
- the radiation shield around the helium reservoir is at a fixed temperature and this can be useful to cool windows or other devices

The liquid nitrogen and liquid helium reservoirs are thermally isolated by using

- low thermal conductivity materials
- high vacuum chamber between the reservoirs and room temperature (OVC)
- multi-layer superinsulation

The dewar is vacuum insulated. The outer vacuum chamber (OVC) of the dewar will be fitted with a large diameter pressure relief valve at the base (or side) of the dewar. This ensures that it is not possible to build up a dangerously high pressure in the OVC.

Warning **Do not tamper with this safety device or attempt to modify it.**

Helium recovery systems

Helium gas recovery systems are often used to collect the exhaust gas from cryostats. They are useful for the following reasons:

- to allow the gas to be liquefied and re-cycled
- to collect gas for other uses (for example vacuum leak detection)
- to prevent air from entering and contaminating the cryostat
- to conserve the Earth's helium supply.

A typical recovery system consists of a low pressure gas collector, a compressor and high pressure gas cylinders to store the gas. Many different cryostats are usually connected to a central low pressure gas collector. The recovery system typically has non-return valves strategic points to make sure that the cryostats do not interact, and the system operates slightly above atmospheric pressure to reduce the risk of contaminating the gas if there is an air leak. The compressor should be specifically chosen for use with helium because of its large heat of compression.

Many factors affect the financial implications of building and using a helium recovery system. In particular it is important to consider:

- the cost of liquid helium in your laboratory
- the cost of installing and running a recovery system and liquefier

If you do use a recovery system you should take precautions to make sure that you recover as much gas as possible and avoid contaminating the gas with air or other substances.

Useful reference books

The following books may be found useful as background reading.

Experimental Techniques in Low Temperature Physics,
by G.K.White, Oxford University Press, ISBN 0-19-851381-X

Experimental Principles and Methods below 1 K,
by O.V.Lounasmaa, Academic Press, ISBN 0-12-455950-6

Low Temperature Laboratory Techniques,
by A.C.Rose-Innes,

London: English Universities Press, ISBN 0-34004778-X
(Probably out of print, but worth looking in the library).

Properties of Materials at Low Temperature, A Compendium.
General Editor Victor J. Johnson, National Bureau of Standards.
Pergamon Press, 1961.

Vacuum Technology its Foundations Formulae and Tables
Leybold Heraeus GMBH.

Superconducting Magnets
Martin N. Wilson,
Clarendon Press, Oxford, 1983, ISBN 0-19-854805-2.

Eléménts de Cryogénie,
R.R. Conte (in French).
Masson & Co, Paris, 1970. (Probably out of print, but very useful).

Elementary Practical Cryogenics
Technical Notes and Glossary of Terms.
N.H.Balshaw, Oxford Instruments Ltd.

Introduction to Thermometry below 1 K
(A review of the available techniques)
Oxford Instruments Ltd., Ultra Low Temperature Group, 1990.

Safety

Contents

Safety Matters

For cryogenic and high magnetic field systems

Warning This booklet contains essential safety information and warnings which could help you to reduce the risks when you are using a cryogenic or high magnetic field system supplied by *Oxford Instruments*. Make sure that no one is allowed to use the system without reading the relevant parts of this booklet.
See page 6 to find out which parts you need to read.

Scope The booklet covers the hazards that you could commonly encounter with liquid helium and liquid nitrogen cryostats, the vacuum systems associated with them, and superconducting magnets supplied by *Oxford Instruments*. It does not describe the law for any country and it does not cover any other cryogens. If you find any errors or omissions or have any other suggestions please tell us about your experiences, so that we can continue to improve this booklet. Your experiences may help others.

Training Proper training by a competent person with local knowledge is essential because all cryogens are potentially hazardous; this booklet is not a replacement for such training.

Note Please note and observe any warnings and instructions in this booklet, and the Operator's Handbook (which may contain specific warnings and procedures for your system). These documents are essential parts of the system and should be kept with the system for the whole of its life (even if you sell or give it to someone else).

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Contents

In memory of M J Shakles, who prepared most of the drawings for this booklet.

1. Introduction

Oxford Instruments designs and builds cryogenic systems for safe operation. However, it is important that the people using this equipment are aware of the potential hazards when working with liquid nitrogen, liquid helium and high magnetic fields. Most of our customers are responsible people working in a laboratory environment, who want to know the reasons for the recommended procedures. This booklet tries to outline the most common hazards in appropriate technical terms for them.

The booklet should be used by the people who are operating the system, not just by senior staff. Keep it close to your cryogenic system and use it to remind yourself about the correct procedures. There are some very good books on the subject of safety, and these should be used. One good example is *Cryogenics Safety Manual - a guide to good practice* by the British Cryogenics Council, (ISBN 0-85298 5010).

All cryogens are potentially hazardous, and a knowledge of their properties will help you to understand why precautions are necessary. Liquid helium (LHe) and liquid nitrogen (LN_2) are less dangerous than some other cryogens, because they are neither poisonous nor flammable. It is tempting to neglect the recommended precautions because you see other more experienced users ignoring them. However, most experienced cryostat users have seen at least one bad accident if they are honest. Even small burns are extremely painful and take a long time to heal. If you are not so lucky you may be blinded or even killed, so think carefully about the consequences of ignoring good advice.

If you are already skilled in the use of cryogens and high magnetic fields you may feel that it is safe to use your professional judgement and decide not to follow all of the recommended procedures. Your knowledge of the signs which indicate that a hazard is developing may help you to avoid most of the risks. However, other less experienced people around you may not understand these signs, and they may follow your example.

1.1. Conventions used throughout this booklet

The following words are used throughout this booklet to draw special attention to the most important messages. However, the paragraphs which are not marked should still be read carefully as they either describe additional rarer hazards or give further explanations.

Danger The word "Danger" is used to indicate a situation which is likely to cause death or serious injury if the instructions are not followed carefully.

Hazard "Hazard" is used to draw attention to a serious risk.

Warning "Warning" indicates that the hazard may cause injury.

Caution "Caution" indicates that there may be a risk of damage to equipment.

1.2. *Which sections should you read?*

It may not be necessary for you to read the whole of this booklet, since it is designed to cover most of our cryostats and superconducting magnets. This page should help you to find out the parts that are relevant to you. Before you start to use any cryogenic or vacuum equipment you should be properly trained by a competent person. Contact your Safety Officer, and arrange for the necessary training, and then use this booklet as a summary of the hazards you are most likely to encounter when you are using equipment supplied by *Oxford Instruments.* Remember that it is your responsibility to ensure the safety of all personnel, equipment, services, or data links in or near your laboratory.

1.2.1. *If you are setting up a laboratory*

If you are designing a new laboratory or planning to install new equipment in an existing laboratory section 1.4. should be useful.

1.2.2. *If you are using a cryogenic system (without a magnet)*

If you are using a cryogenic system (without a magnet) it is important that you read the following sections which give you advice on the essential safety procedures:

1.3. Common hazards in laboratory cryostats
2. Using vacuum and high pressure systems
3. Operating cryogenic systems
5. Working with electrical equipment

If your system is too heavy to lift by hand you should also read section 6. which explains how to lift heavy systems safely.

Section 7. gives you background information, and this may help to explain the reasons for these procedures. We recommend that you read this too because a good knowledge of these properties will help you to run the system safely.

1.2.3. *If you are using high magnetic field systems*

If the system you are using contains a magnet it is important that you read all sections listed in section 1.2.2. and the following sections which give you advice on the essential safety procedures:

4. Operating magnet systems
6. Lifting and transporting heavy equipment

Sections 7. and 8. give you background information, and this may help to explain the reasons for these procedures. We recommend that you read them too because a good knowledge of these properties will help you to run the system safely.

1.2.4. *If you are using a nuclear orientation thermometer*

The procedures for using a low activity ^{60}Co gamma ray source are given in section 9.

1.3. Common hazards in laboratory cryostats

Hazards The following list shows the range of hazards that you may encounter when you are using laboratory scale cryostats. However, you can protect yourself against all of these hazards by following the correct procedures as described in this booklet or in the Operator's Handbook.

- extreme cold and the risk of cold burns or frostbite
- asphyxiation (if the atmospheric oxygen is displaced)
- fire and explosion hazards (through oxygen enrichment)
- high magnetic fields affecting medical implants
- high magnetic fields resulting in large attractive forces
- electrical hazards
- vacuum hazards
- high pressure hazards
- radioactive sources (sometimes used as thermometers etc.)
- lifting and moving heavy equipment

Hazard **If you suspect that there is a fault with your system (perhaps indicated by one of the following signs), empty it and repair the fault immediately.** It is tempting to try to finish the experiment you are doing , but the fault may lead to additional unknown hazards.

Signs that a hazard might be developing:

- unusually high (or low) boil off
- unusual condensation of atmospheric moisture
- unexpected patches of frost on the outside
- faulty valves

These notes cannot cover all aspects of the operation of a cryogenic system. In particular, they do not cover:

- the use of more dangerous cryogens (liquid air, liquid oxygen, liquid hydrogen etc.)
- the operation of large scale cryogenic equipment or storage tanks.

If you plan to use the system we have supplied as part of a larger system you must consider all of the potential hazards.

Warning The Operator's Handbook for your system may give additional information about hazards not covered by this booklet, and specific procedures to follow.

If you are in doubt about any aspect of the operation of the system you should contact a local expert or your supplier. If you sell or give your system to someone else you are obliged to warn them in writing about the potential hazards, and you may like to use this booklet to do so.

1.4. *Setting up your laboratory*

When you are setting up your laboratory you should:

- design the laboratory with safety in mind
- consult an expert who has experience of setting up other similar laboratories
- set up a procedure to be followed by anyone using the equipment
- make sure that the correct procedures and local regulations are always followed
- train all personnel and supervise them properly
- display clear notices to warn people that they are entering a potentially hazardous area. Remember that even if the door is locked, some other people have keys. For example, cleaners and security staff are often working when there is no one else around, and they are at risk too
- tell the local safety officer about your system, and ask her to make local emergency services aware of the hazards, as this may affect the procedures they follow when they are dealing with fires or other incidents
- consider carefully whether the floor in your laboratory is strong enough to take the weight of the system. Seek professional advice if necessary
- if you are using a superconducting magnet system, consider whether there are any large magnetic items close to the system (e.g. magnetic beams in the floor) and check whether the stray field will affect other equipment in your laboratory or in other rooms nearby (even on other floors)
- consult your local fire authority about the equipment you should install in case of a fire. They may require that portable fire fighting equipment is non-magnetic. Ask them to check whether your smoke detectors will be set off by helium gas, (as some are)
- install an overhead crane (or other lifting equipment) capable of lifting heavy equipment safely
- make sure that the laboratory is sufficiently well ventilated. If there is any doubt, install sensors which will warn you if the oxygen level becomes dangerously low
- refer to relevant local health and safety publications

1.5. *Working alone*

Warning **Do not work alone. It can be dangerous.** If you have an accident there will be no one there to help you.

If you do have to work alone and you have decided that it is worth taking the risk, arrange to call someone regularly to confirm that you are safe. If they do not receive your call at the expected time they can then raise the alarm.

2. *Using vacuum and high pressure systems*

2.1. *Vacuum pump operation*

Warning **If rotary pumps are operated without good oil mist filters, they emit a mist which represents a health hazard.** Do not breathe these fumes. The exhaust from the pump may be piped away from the laboratory if a suitable filter is not available.

2.2. *Vacuum vessels*

Warning **Vacuum spaces in cryogenic systems should be protected with an overpressure relief valve for the following reasons.**

If a system is operating for an extended period, a small air leak may go unnoticed. The air that leaks into the vacuum space is likely to freeze onto a cold surface or be absorbed by a sorption pump. Only when the system is warmed up does it become apparent that a large volume has been collected, and this may expand to fill the vacuum space to a pressure higher than it can safely withstand.

If one of the vessels filled with cryogenic fluid becomes damaged, the fluid may be released into the vacuum space, where it breaks the vacuum and is rapidly warmed. Large relief valves are required on the liquid and vacuum spaces to vent the gas generated, and all our systems are protected in this way.

2.3. *Collapsing tubes*

Caution **Do not evacuate vessels which are not designed to work under vacuum, and only vent vacuum vessels slowly.** Take care to avoid evacuating chambers within a cryostat which are not designed to withstand external pressure. Most commercially manufactured cryostats are protected by support bands to prevent them from collapsing or exploding in normal operation, but check the Operator's Handbook to make sure.

Some systems may be damaged if you vent a vacuum space too quickly. The shock of the sudden pressure increase may cause an otherwise safe tube to collapse. Some systems must be vented slowly to allow the pressure to equalise in different parts of the system.

2.4. *High pressure cylinders*

Warning **Know the law and follow it.** High pressure cylinders are often used to store gases (typically at pressures up to 200 bar). Most countries have laws about using them.

- chain them to a fixed object or keep them in specially designed trolleys
- only use approved and tested high pressure fittings

These cylinders become dangerous projectiles if they are ruptured or the valve is knocked off, and they can break through thick walls or travel hundreds of metres.

3. *Operating cryogenic systems*

3.1. *Introduction*

Hazard **When you are handling cryogens you have to protect yourself from the potential hazards. Make sure that you know enough about their properties, and take appropriate actions.** In particular, you should protect yourself from:

- extreme cold
- asphyxiation
- fire and explosion hazards
- hazards associated with vacuum systems

Warning **You can protect yourself from the extreme cold by wearing suitable clothing but you can only protect yourself against the other hazards by making sure that they do not occur.**

Warning **Label vessels clearly to indicate their contents.** This helps other people to decide what precautions they need to take to ensure their own safety. Remember that it is your responsibility to keep the working environment safe for other people, and they may hold you liable if you don't.

3.2. *Protective clothing*

Warning **Wear protective clothing.**

- wear goggles to protect your eyes. Eyes rarely heal well!
- use loose fitting gloves so that you can remove them easily in case you spill liquid inside them
- wear overalls or similar clothes, preferably without pockets or turn-ups
- wear sensible shoes (not sandals) and make sure that your trousers cover the top of your shoes to prevent spilt cryogens running into your shoes

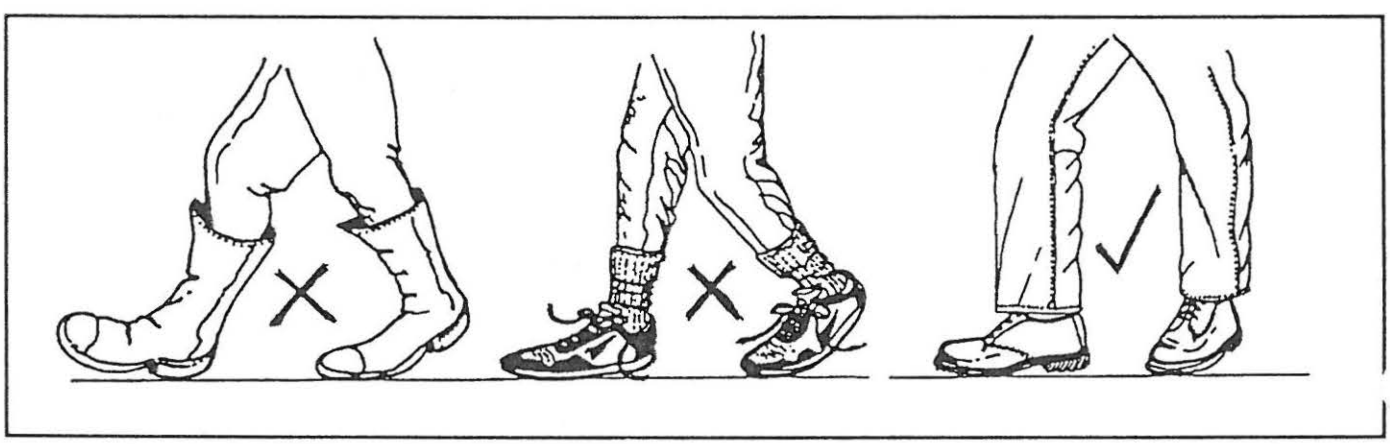


Figure 3.2. Wear sensible shoes, not sandals

3.3. *Handling cryogens*

Warning **Cryogens will boil violently and splash when they come into contact with warmer objects. Wear appropriate protective clothing and handle cryogens carefully.**

When you insert an open ended pipe into the liquid, block off the warm end until the other end has cooled down. If you don't, cold liquid is likely to squirt out of the open end under self-generated pressure. Never point pipes towards someone else.

Danger **Only use containers specifically designed for use with particular cryogens**:

- they must be made of suitable materials. Many materials (even some common steels) become dangerously brittle at low temperatures
- bungs (or stoppers) should be tied to the top of the container. This prevents them from being lost, and ensures that they cannot be blown out by a high pressure and become dangerous projectiles
- if you are using a magnet system, the cryostat and transport vessel should be constructed of non-magnetic materials

Warning **Only use suitable metal tubing to transfer cryogens.** Do not use rubber, silicone rubber, or plastic tubing. Although polythene and nylon are sometimes used, this should not be taken as a recommendation. Any materials you decide to use should be carefully tested in safe conditions, and only used if approved by the manufacturer.

Figure 3.3. Cryogens always boil and splash when they come into contact with warm objects

3.4. *Protection against extreme cold*

Warning **Wear protective clothing** - see section 3.2.

Do not wear wet clothing - it could freeze to your skin.

Caution **Protect your equipment from extreme cold too.** Some examples of the effects of extreme cold on the equipment in your laboratory are given below.

Cryogens spilt on vacuum equipment may freeze rubber vacuum seals, and cause loss of insulating vacuum. Don't allow the top flange of your system to get too cold, as this might cause the vacuum to fail. (Warm it with a hot air blower if ice starts to collect).

If you spill cryogens on electrical cables, they may freeze and fracture the insulating layer causing electrical hazards. Keep all the cables above the level where cryogens may be spilt on them, not on the floor.

Spilt cryogens can also condense the moisture from the air to form a thick mist which can obscure your vision. If you are enveloped in a cloud of cold gas you may lose your balance and fall. This is particularly dangerous if you are standing on a ladder.

The floor of your laboratory may also be damaged if cryogens are spilt over it. In particular, plastic tiles may become very brittle, or may be cracked by rapid cooling.

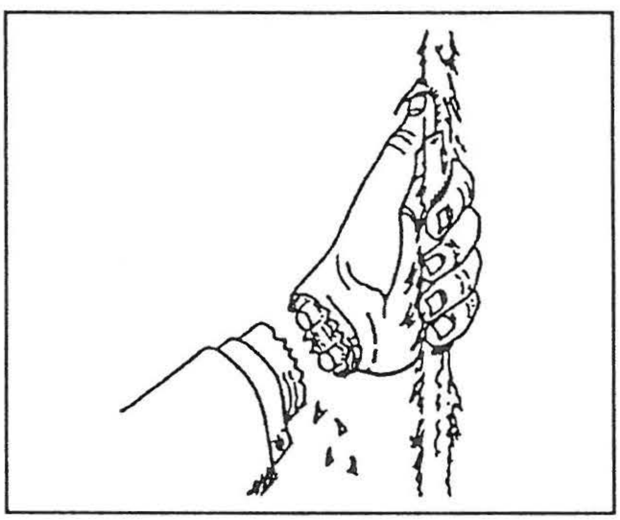


Figure 3.4. Flesh may freeze and stick to cold surfaces

3.5. *Protection against asphyxiation*

Danger **Make sure that there is good ventilation in any room where cryogens are stored or used.** If all or part of the oxygen is removed from the atmosphere you may become unconscious without warning. The effects of asphyxiation depend on the oxygen concentration but **there is no sensation of breathlessness to warn you**

that you are being asphyxiated; breathlessness is a symptom of a high concentration of CO_2 (not a low concentration of oxygen). It is important to make the relevant preparations before you put yourself at risk. If the oxygen level is being reduced slowly the first symptoms may be increased pulse and breathing rate, with impaired judgement, but the very first symptom you notice may be that you cannot stand up or even crawl. By this stage it is already too late for you to help yourself.

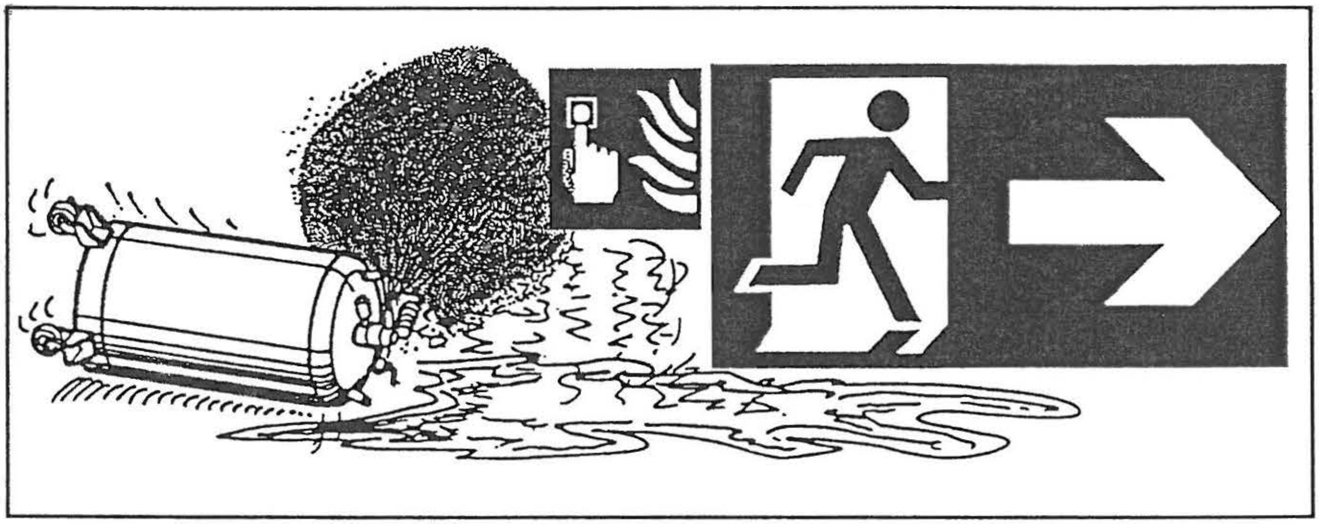


Figure 3.5. If a large amount of liquid is spilt, clear the room immediately, and consider sounding the fire alarm

Warning **Protect yourself against asphyxiation as follows:**

- ensure that there is sufficient ventilation
- install sensors which will sound an alarm if the oxygen level is too low unless you are sure about the effectiveness of the ventilation in a room
- leave the room immediately if a large amount of cold gas is released quickly (for example after a superconducting magnet has quenched)
- ventilate the room well if you are precooling a large system with liquid nitrogen
- leave the room immediately if a large amount of liquid is spilt. Consider sounding the fire alarm if there is likely to be a fire hazard, or to clear the area quickly
- do not accompany storage or transport vessels in confined spaces (especially in lifts, elevators or enclosed vehicles)
- use a suitable exhaust system to pipe exhaust gases away from the cryostat to the atmosphere or into a helium recovery system
- if you store cryogenic liquid vessels in a room which is not well ventilated, put warning signs on the doors so that no one enters the room until it is well ventilated
- remember that cold nitrogen gas tends to collect near the floor, and helium gas near the ceiling. (See Figure 3.6.)

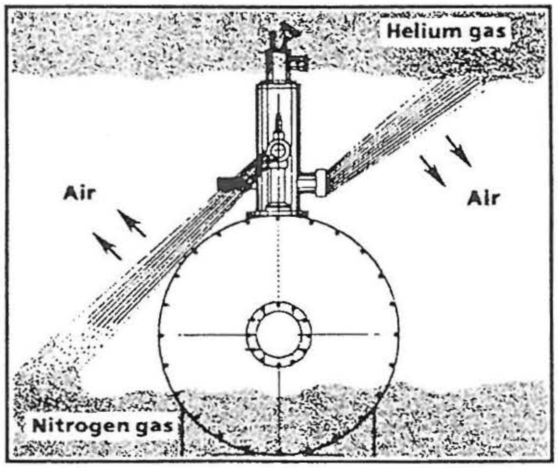


Figure 3.6. Gas from the cryostat displaces atmospheric oxygen

3.6. Protection against fire hazards

Hazard **Oxygen enrichment may cause spontaneous combustion.** Most of the fire hazards encountered in normal laboratory scale cryogenic systems are caused by oxygen enrichment. Liquid oxygen can condense from the air onto surfaces which are at temperatures below 90 K. You can often see liquid air running from a cold helium recovery line if a helium transfer is carried out too quickly or if a magnet has quenched. **This liquid can cause fires!**

Liquid nitrogen in an open bucket tends to condense atmospheric oxygen into solution because the boiling point of oxygen is above that of nitrogen. In equilibrium, the liquid may have an oxygen concentration higher than 50%. Any combustible materials exposed to this liquid can burst into flames spontaneously. A foam plastic bucket containing liquid oxygen is potentially explosive. Liquid air and liquid oxygen (LOX) *can* be handled safely, but only by those who have had the necessary training.

Hazard **Avoid the risk of fire by taking these precautions:**

- make sure that there is no oil or grease in a position where it may be exposed to liquid air (even if it is liquefied by accident)
- do not use compressed air to blow liquid nitrogen out of a cryostat, because the oxygen in the compressed air will condense into the liquid very easily
- do not smoke and forbid smoking in the areas where cryogens are handled
- make sure that suitable fire extinguishers are available
- train people to use the fire extinguishers properly

Danger **If a fire breaks out, sound the fire alarm, and make sure everyone leaves the area.** Special expertise is required to put out these fires safely, so if you have not been trained how to do it, find someone who has. If you choose the wrong type of fire extinguisher or you do not use it properly you may block the exhaust vents of the

cryostat with ice, and if the exhaust gases are not allowed to escape through a suitable relief valve the system will probably explode.

Warning **After the fire has been extinguished make sure that the system is safe.**

3.7. Protection against explosion and blockages

These guidelines are intended to apply only to preventing explosions caused by accidentally blocking the exhaust of a cryostat, or warming up a cryostat which has accidentally condensed contamination from the atmosphere onto cold surfaces. This should be sufficient for most laboratory systems. Flammable or explosive cryogens which are likely to cause explosions because they have caught fire are not covered by this booklet.

Warning **If the exhaust ports are connected to pumping lines or a helium recovery system, make sure that the lines have a large enough diameter for the expected gas flow. In general, you should assume that the diameter of the tube should be at least as large as the diameter of the exhaust port.**

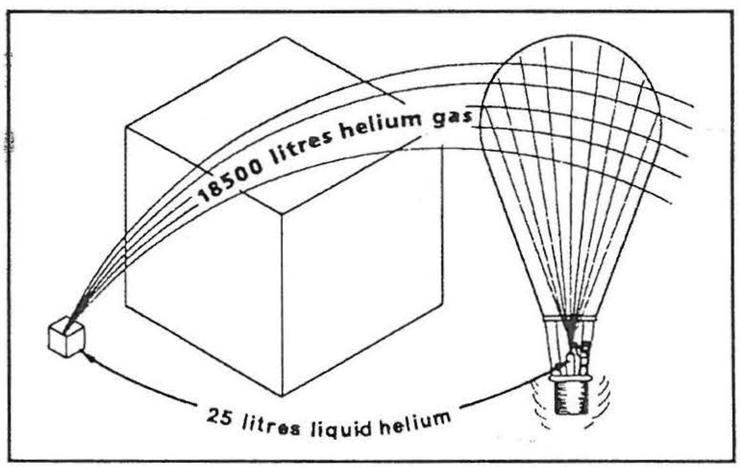


Figure 3.7. Cryogenic liquids boil and expand to generate a large amount of warm gas

Danger **The helium reservoir exhaust must be fitted with a non-return valve or connected to a helium recovery system.** This prevents ambient air leaking back into the cryostat. The valve should be at least large enough to handle the normal gas flow during a liquid helium transfer.

Warning **Systems should also be fitted with large pressure relief valves to allow the helium gas to leave the system quickly. If your system was fitted with one of these valves when it was supplied, it must never be run without it.** In the event of a magnet quench or major vacuum failure the evaporated helium will be vented safely through the valve(s).

Danger **All relief valves on the system should be large enough to handle the maximum possible gas flow, caused by all the different failure modes happening together.** Rapid failure of the insulating vacuum can make all the liquid in the cryostat evaporate very quickly.

Warning **Make sure that all of the system's exhaust vents are kept clear of ice.** If possible, arrange for the vents to be at a temperature higher than 0°C, so that water does not freeze there. You can sometimes do this by fitting a short length (say 100 mm) of plastic pipe over the vent tubes; they will be covered with ice, but if they are long enough, the open end will be warm enough to stay dry. Make sure that systems are not stored where they might be exposed to rain or moisture, unless they are properly protected.

Warning **Check for blockages regularly and often.** Check the system boil off regularly. If there is no boil off and you know that the system is not empty check whether a blockage is preventing the natural boil off. The pressure inside the cryostat will rise until it reaches a dangerously high level. Always fit a non-return valve to at least one of the liquid nitrogen vessel ports. "Bunsen valves" (which are sometimes recommended for this application) are a crude form of non-return valve made from rubber tube. Do not rely on them to protect a vessel effectively because they do not seal well, especially when frozen.

Hazard **Refer to section 3.11. and the Operator's Handbook for your system when warming up a system.** It is particularly important to consider the explosion hazard when you are warming up the system, especially if it has been cold for a long time. Small leaks may go unnoticed, and any air that leaks into the vacuum spaces may then be cryopumped onto the cold surfaces. This expands to form a large volume of gas as the system warms up.

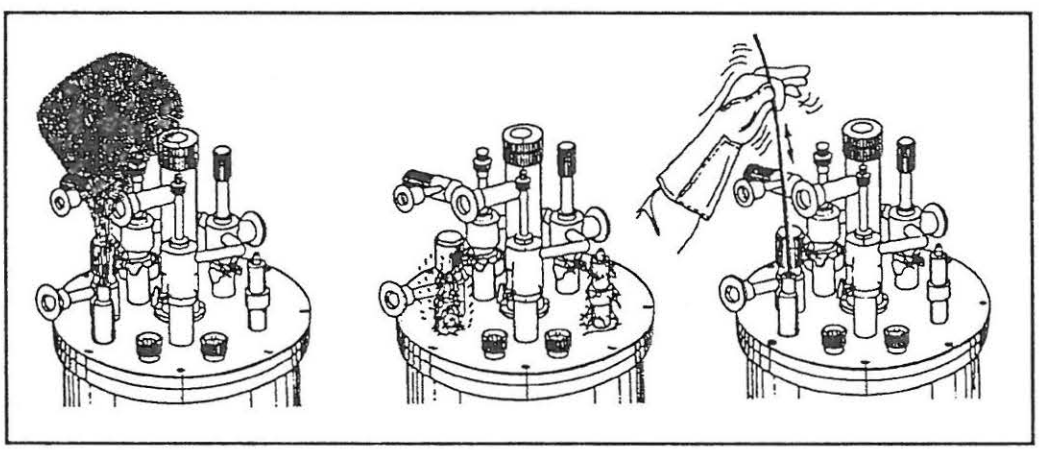


Figure 3.8. Check for blockages regularly and often, and clear them as soon as possible

3.8. *Clearing blocked tubes*

Hazard **If you find that all the vents of a vessel are blocked, you should quickly and calmly evacuate the area and then find an 'expert' to help you clear it.** The expert will be better qualified to decide how much time to spend trying to clear the blockage before it is too dangerous to be near the cryostat. If only one vent is blocked and the vessel is still venting safely through another vent, it may not need urgent attention but you should still clear the blockage as soon as possible.

Warning **Wear protective clothing - cold gas burns. If you cannot find an expert you can try to clear the blockage** using a piece of warm copper tube, but remember to wear thick gloves and goggles or a full face mask. Warm the tube with a hot air blower before pushing it down the vent to melt the ice. When the tube clears the blockage, gas can escape through the middle of the tube. Alternatively, pass a continuous supply of clean dry helium gas through the tube onto the ice plug, and heat the tube to warm the gas. You can then retire to a safe distance until the blockage is cleared.

Danger **If you cannot clear the blockage**, consider moving the vessel to a safe place. Evacuate everyone from the area, and do what you can to reduce the secondary risks from the effects of a possible explosion.

3.9. *Liquid nitrogen - specific techniques*

Liquid nitrogen is often stored in open topped dewars and it is therefore exposed to the air. Since liquid oxygen liquefies at a higher temperature than liquid nitrogen, oxygen from the air will condense into the nitrogen. If this is allowed to continue, the oxygen concentration may become so high that the liquid becomes as dangerous to handle as liquid oxygen. This applies particularly to wide-necked dewars.

Warning **Open dewars should at least be covered to minimise contact with the air.**

Liquid nitrogen can be poured into small vessels using a funnel. If the storage dewar is too big to be tipped over, or if it might be damaged, the liquid can be transferred by pressurising the storage dewar (but not with compressed air). Uninsulated transfer lines can be used but losses should be expected. **Always make sure that one end of a warm tube is closed before you put it into a dewar of liquid nitrogen.**

Warning **Make the following daily checks on liquid nitrogen vessels:**

- check the boil off and investigate if it is higher or lower than expected
- check the liquid level and top up as necessary
- check that the relief valves have not been tampered with
- after a liquid helium transfer into a liquid nitrogen shielded helium vessel, check that the nitrogen vents are still clear

3.10. Liquid helium - specific techniques

Danger **Liquid helium may cause blocked vents or oxygen enrichment.** Liquid helium is the coldest of all cryogenic liquids. It will therefore condense and solidify any other gas coming into contact with it. Any surfaces cold enough to condense air in normal operation could also increase the oxygen concentration to a dangerous level, and they should be cleaned to 'oxygen clean' standards. This is why liquid helium containers often have labels saying "Flammable liquid" even though the liquid is not flammable.

Warning **Insert warm objects into liquid helium vessels very slowly.** This makes sure that they are well cooled by the cold gas before they reach the liquid and:

- reduces the hazard from rapid boiling which produces a jet of cold gas
- considerably reduces the consumption of liquid, saving money

Always make sure that one end of a warm tube is closed before you lower it into liquid helium.

Warning **Liquid helium must be kept in specially designed storage or transport vessels.** Dewars should have a non-return valve fitted in the helium exhaust line at all times, or be connected to a helium recovery system, so that air does not enter the neck and block it with ice.

Caution If possible, liquid helium should be kept at a slight positive pressure, so that if there is a leak, helium may leak out but air does not leak in.

Caution If you transfer liquid helium into a liquid nitrogen shielded dewar check that the nitrogen vents are clear. The cold helium gas sometimes cools the liquid nitrogen reservoir to below 77 K, (sometimes called 'supercooling'), so that it starts to condense gas from the air. The water vapour in the air then freezes in the vents, and may block them. Always make sure that at least one non-return valve is fitted to these vents.

Warning **If a superconducting magnet quenches releasing helium gas to the atmosphere you should evacuate the laboratory immediately and allow good ventilation until the helium gas has been dispersed.** If you do not do this you may be asphyxiated. There is always a risk of the magnet quenching (or going resistive). The stored energy in the magnet then evaporates most of the liquid helium very quickly. The helium recovery system is unlikely to be able to handle such a large amount of gas (perhaps 20 m^3 or more in a few seconds), and the relief valves will release the excess gas into the laboratory, displacing the air.

Warning **Make the following daily checks on liquid helium vessels:**

- ensure that the non-return valve (or recovery system) is still fitted to the exhaust
- check that all other ports on the top plate are sealed properly
- check the boil off
- check the liquid level and re-fill if necessary

3.11. *Warming up a system*

Hazard **Take care when you warm a system to room temperature.** All the chambers in the cryostat must be free to vent safely, even if you think that they are empty. If the system has been cold for a very long time, or there is a leak into the cryostat, air may have been cryopumped onto the cold surfaces inside the system. There is no way to tell whether this has happened. As the air evaporates its volume may increase very quickly, and the vessel may not be strong enough to take the resulting high pressure.

Warning **Read the Operator's Handbook and follow the instructions carefully.** Remember:

a 1 litre of liquid helium expands to 750 litres of gas at room temperature and atmospheric pressure (NTP), or becomes 1 litre of gas at 750 bar if it is not free to expand.

b 1 litre of gas at 4.2 K expands to 70 litres NTP, or becomes 1 litre of gas at 70 bar if it is not free to expand.

c even if all of the liquid and gas has been removed, it is possible that some air is frozen in the vessel or the pumping line, and this will expand in a similar way.

d **until you warm up the system, you cannot tell whether there is any frozen air in one of the chambers**. For your own safety, assume that it is there.

3.12. *Dangerous cryogens*

Danger **You need special training.** The correct handling procedures for the less common cryogens which may be toxic, flammable or explosive are not included in this summary. If you are using cryogens other than liquid nitrogen or liquid helium it is important that you ask your safety officer to make you aware of the potential hazards.

3.13. *First aid*

If any of the cryogenic liquids come into contact with eyes or skin, immediately flood the affected area with large quantities of cold or tepid water. Never use hot water or dry heat, which could cause further burning to the damaged area. If the skin is blistered, the burns are extensive, or the eyes have been affected, seek medical advice immediately. Cover burns with sterile dressings. Do not allow the victim to smoke or drink alcohol.

If the victim is suffering from dizziness or loss of consciousness due to asphyxiation:

- make sure that you are safe first
- summon medical help immediately
- move the victim to a well ventilated area if it is safe to do so
- apply artificial ventilation or resuscitation if necessary

If the victims lungs have been exposed to cold gas enough to cause distress, or if in doubt, take him or her to hospital immediately.

4. *Operating magnet systems*

4.1. *Introduction*

Many cryogenic systems include superconducting magnets which operate at very high fields. So far (1994) there is no conclusive evidence that magnetic fields can directly affect health, but the effects of the field (described in section 8.) can be very hazardous.

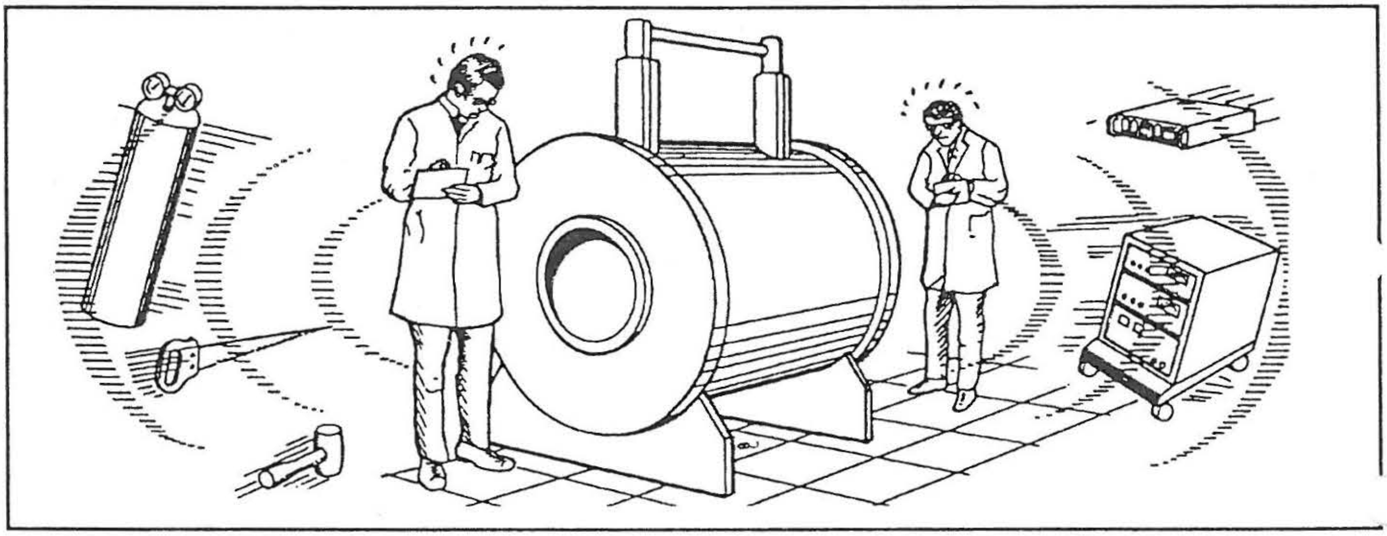


Figure 4.1.1 Magnetic items may move uncontrollably towards the cryostat, and may trap you or damage the system

Hazard

Consider the following hazards (at least):

- magnetic items may move suddenly and uncontrollably towards a magnet, and most tools are magnetic
- someone could be trapped between a large magnetic item and a cryostat, resulting in severe injury or death
- medical electronic implants (e.g. pacemakers) may be affected by a magnetic field
- the magnetic field is three dimensional so the field may affect rooms on the floors above and below your laboratory, as well as on the same floor
- magnets may suddenly go resistive (or 'quench') and release their stored energy into the liquid helium
- remember all the potential cryogenic hazards summarised in section 3.
- magnetic data on credit cards or disks may be corrupted

Every magnet site should be reviewed individually to determine precautions to be taken against these hazards.

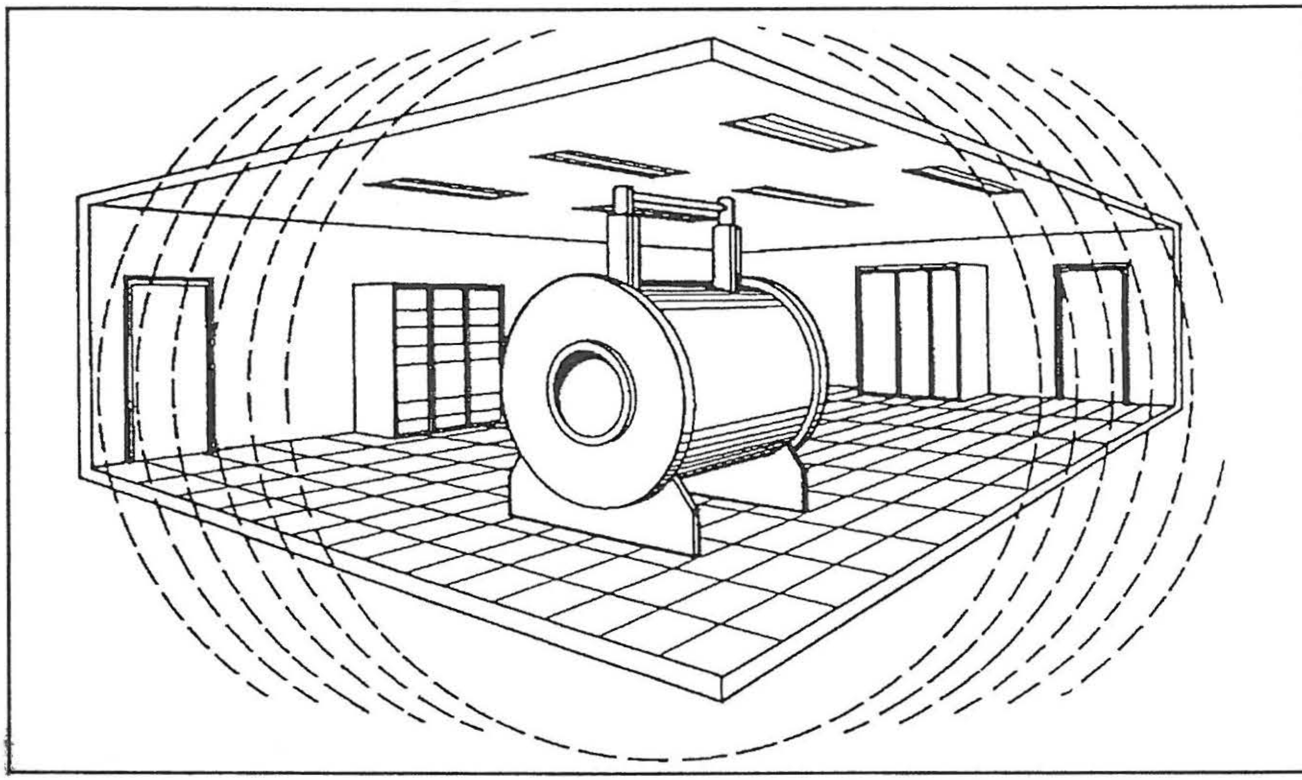


Figure 4.1.2   The field is three dimensional and affects areas on floors above and below your laboratory.

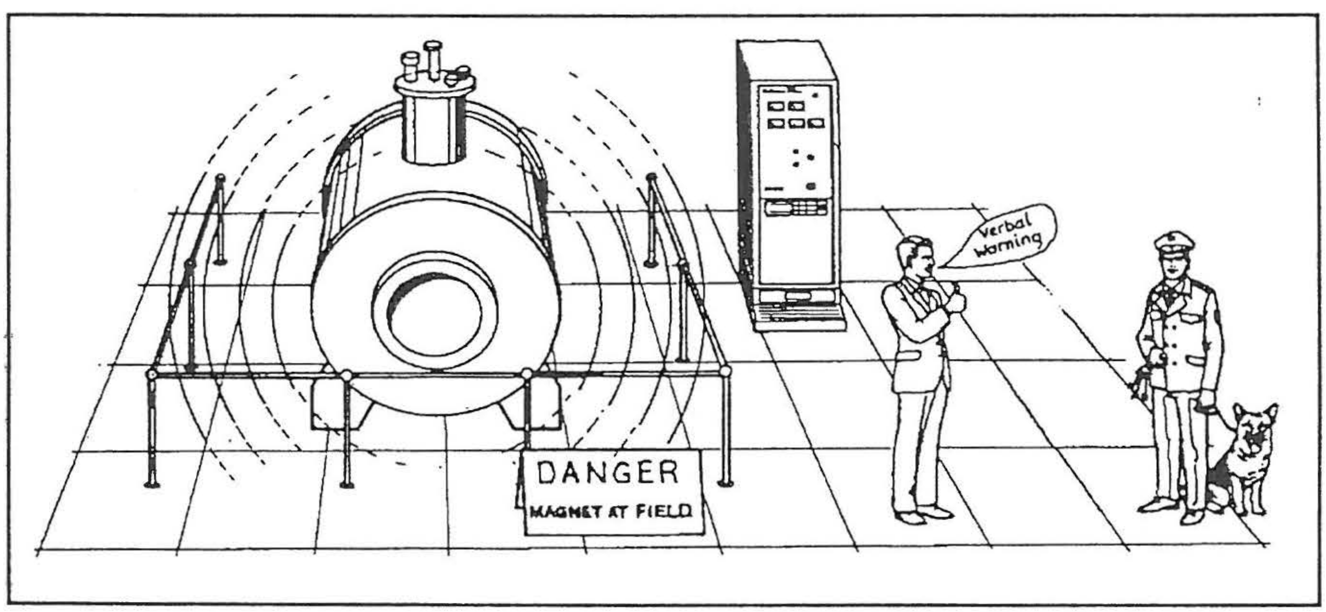


Figure 4.1.3   Give a verbal warning to anyone entering your laboratory. Remember the cleaners and security staff, and erect warning signs.

4.2. *Before running the magnet*

Hazard

Before you start to run a magnet:

- ensure that all loose ferromagnetic objects are moved to a safe distance
- check that the protection circuit has been fitted, and electrically ground the cryostat
- check that the rubber insulating boot has been fitted over the current lead terminals
- display warning signs (preferably illuminated) at all the laboratory doors, to remind people that the magnet is operating
- display warning signs giving notice of the possible presence of magnetic fields and of the potential hazards in all areas where the field may exceed 5 gauss
- ensure that all electronics and interfacing equipment supplied by *Oxford Instruments* are placed in areas where the field level will be less than 100 gauss
- assess the safe working field level of all other equipment and take appropriate action
- check that the helium reservoir is protected by suitable pressure relief valves in case the magnet quenches
- consider carefully whether the exhaust gas or gas released by a pressure relief valve in the event of a quench could injure someone working on the system. If necessary, put guards around the hazardous regions
- check that there is enough liquid helium in the system
- on optical systems, check that the windows are guarded as much as possible so that they cannot be broken by small loose magnetic items

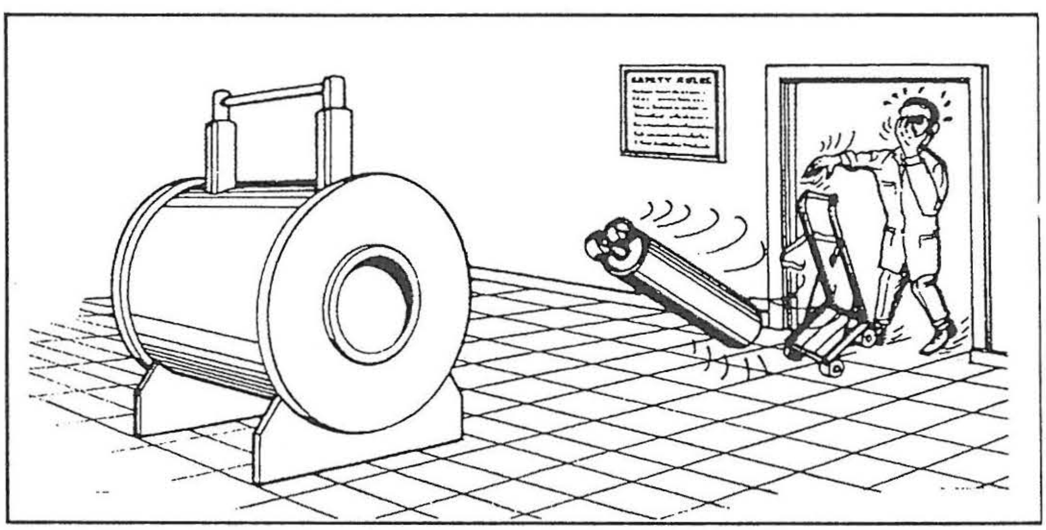


Figure 4.2. How do you think he feels now? It is too late to do anything about it.

Unless specifically stated in the Operator's Handbook, all magnets supplied by Research Instruments must be fitted with a protection circuit, usually mounted within the cryostat. In the event of a quench it will:

- dissipate the stored energy outside the magnet
- protect the users, the magnet and the wiring from dangerously high voltages

4.3. *While the magnet is at field*

Warning **While the magnet is at field make the following checks regularly:**

- check the liquid helium level and refill if necessary
- check that the warning signs are still in place
- do not bring magnetic objects too close to the magnet
- only use non-magnetic storage/transport dewars and non-magnetic trolleys for liquid helium and liquid nitrogen
- remember that even non-magnetic electrically conductive materials may experience a force or resistance to motion due to induced eddy currents
- give a verbal warning to people entering the room
- ensure that there is sufficient ventilation

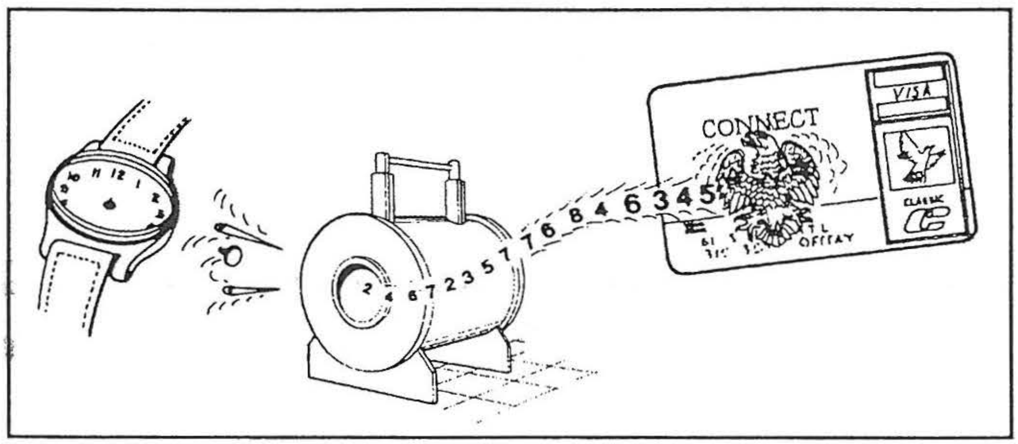


Figure 4.3. Stray magnetic fields affect other equipment around the cryostat

4.4. *Superconducting magnet quenches*

There is always the risk of a quench, even in a very reliable and stable magnet. External factors can affect the stability of the magnet, so you should be prepared for the potential hazards. A large amount of cold gas will be generated very quickly, and the field change may affect other items in the laboratory. If you are using an *Oxford Instruments* power supply for your magnet, the output current will automatically be switched off safely.

Hazard **If your magnet quenches:**

- in poorly ventilated areas, evacuate the room immediately and do not enter the room again until you know that there is sufficient oxygen in the air
- wait for a few minutes before you go near the cryostat again
- check that pressure relief valves have sealed properly, so that they do not let air back into the system
- replace any broken bursting discs (if your system has any)
- check that the nitrogen vent ports are still clear (if your system has any)

5. *Working with electrical equipment*

The following recommendations apply to electrical equipment supplied by *Oxford Instruments* for use with laboratory systems including:

- superconducting magnet power supplies
- temperature controllers
- liquid level meters
- SQUID control electronics

5.1. *Protective ground*

Unless it is being powered from its own internal batteries, the instrument must always be connected to an electrical ground when it is being used, to reduce the risk of electric shocks. The ground wire (green/yellow) in the instrument power cable must be connected to the laboratory electrical ground. Only use extension cables if they have an earth conductor. Do not disconnect the protective ground inside or outside the instrument and do not have external circuits connected to the instrument when its protective ground is disconnected.

Danger **The instrument will not stop working if the earth wire is not connected, and there is no indication that you might be in danger. Make sure that it is checked regularly (and at least annually) by a competent person.**

5.2. *Working environment*

Warning **Do not use electrical equipment in:**

- **rain or excessive moisture**
- **flammable or explosive gases**

Unless specifically stated, our equipment is not designed to be water or splash proof, or to be used in areas where there are flammable or explosive gases or fumes.

5.3. *Repair and adjustment*

Some internal adjustments can be made to electrical equipment supplied by *Oxford Instruments*. Although we do not encourage you to make these adjustments we try to supply you with enough information to allow you to do it safely.

Danger **Lethal voltages are accessible inside the instrument. Disconnect the AC power supply before you remove the covers or fuses. It is not sufficient to switch off the main power switch. Only do this type of work if you are suitably qualified and sufficiently skilled to understand all the risks you are taking.** There may be capacitors inside the instrument and power supply filter which are still charged to a high voltage even after the AC power has been removed. Discharge all of them carefully before you start work.

Danger **Some fault finding and calibration operations can only be carried out with the power connected to the instrument. If you have to reconnect the AC Power supply with the protective covers removed you must remember that you are putting your life at risk.**

5.4. *Superconducting magnets*

When the magnet is at field, it stores a large amount of energy, and it is capable of producing very high voltages. The protection circuit is designed to protect the users and the equipment from these hazards.

Warning *Oxford Instruments* superconducting magnet power supplies are designed to prevent high voltages between the current terminals on the top of the cryostat in the event of a failure in the protection circuit. However, it is possible for the terminals to reach a high voltage with respect to the cryostat, so treat them as high voltage terminals.

Some low loss systems are fitted with special demountable leads which make it safe to disconnect the power supply, and the instructions in the Operator's Handbook should be followed carefully. These systems have special 'shorting plugs' which should be used:

- to help protect the magnet
- to keep the cold electrical connectors free from ice

Otherwise the current leads should not be disconnected while the magnet is at field. If you do disconnect the power supply you risk being electrocuted.

Hazard **Summary of electrical hazards from the magnet:**

- do not run the magnet without the protection circuit connected
- do not modify the protection circuit
- ground all equipment, including the cryostat and electronics
- if the magnet is at field, do not disconnect the magnet power supply unless the system is fitted with suitable demountable leads
- if the leads are demountable, fit the shorting plug properly
- fit the insulating rubber boot to the magnet current leads

6. *Lifting and transporting heavy equipment*

Most countries have rules about lifting heavy equipment, and they are usually strictly enforced by law. Some cryogenic systems are so heavy that they can only be lifted by a large capacity crane, but they may contain very delicate components. If you choose the right way to lift the system you will be able to:

- ensure your own safety
- avoid damaging fragile equipment

Warning **Use the lifting points provided on the system.** Anyone lifting heavy equipment should be properly trained. These notes only cover methods of lifting systems using the lifting points provided. You should avoid lifting by putting a chain or lifting strap underneath the system, as special skills are required to do this safely.

6.1. *Lifting points*

Hazard Most *Oxford Instruments* systems that are too heavy to lift by hand are fitted with lifting points which are designed to carry the weight of the system safely. They are usually positioned so that the system will stay upright when it is lifted. The safest way to lift systems is to use all the lifting points provided. You should use them whenever possible, rather than using a sling underneath the system.

The collar eyebolts used by *Oxford Instruments* are suitable for axial lifting, or non-axial lifting providing that the safe working load (SWL) is reduced by an appropriate factor. They are chosen to be suitable to lift the system provided that the chain or lifting strap is at a small angle to the vertical. In general we suggest that this angle is less than 15° (see figure 6.2.) but you should check in the Operator's Handbook that your system does not have any special lifting requirements.

6.2. *Lifting equipment with an overhead crane*

Danger **Before you use the crane:**

- check that the safe working load (SWL) of the crane will not be exceeded
- check that all other lifting equipment has been tested, that it is currently approved for use, and that you do not exceed the SWL
- never use untested ropes to lift the system
- whenever possible use closed shackles rather than open hooks

Danger **When you are using a crane:**

- make sure that no one is allowed underneath an unsupported load
- always stand clear of the load in case the crane or lifting straps fail
- lift the system slightly clear of the ground and check it for balance and stability before lifting it higher, and don't allow the load to swing
- avoid sudden movements which would impose a high shock load

Danger **Never work underneath an unsupported system hanging from a crane.** If the system falls you may be killed.

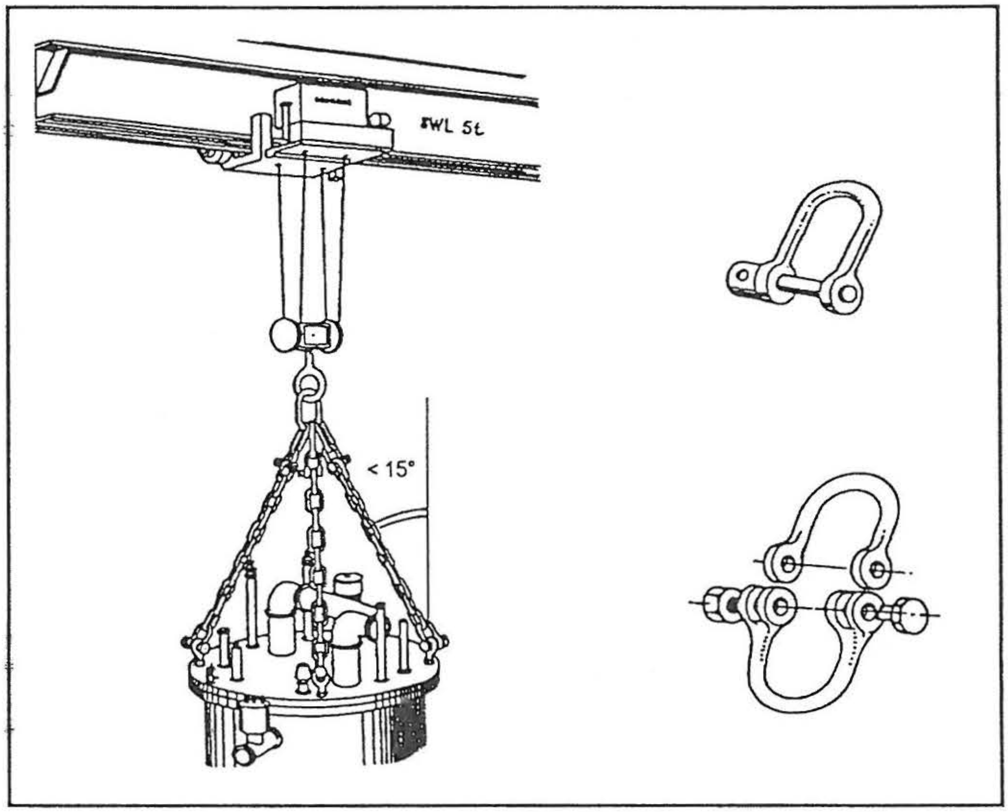


Figure 6.2. Lift a cryostat safely, using suitable shackles (as shown) and tested lifting equipment.

6.3. *Transporting systems safely*

Warning Most systems can be transported safely on a pallet using a trolley or fork lift. However, remember that:

- some tall systems have a high centre of gravity and might fall over easily
- systems should be moved gently because they are fragile

6.4. *Maintenance*

Warning **Have the eyebolts, lifting points and all other lifting equipment regularly inspected by a competent person**, who will check that they are free from cracks, distortion, and any other defects.

7. *Properties of helium and nitrogen*

7.1. *Introduction to this background information*

Liquid nitrogen (LN_2) and liquid helium (LHe) are usually kept close to their normal boiling points in insulated storage vessels (dewars). Recommendations about the way to handle these cryogens are given in section 3. and this section is intended to provide the background information to help you to understand the reasons for the recommended procedures.

7.2. *Properties of LN_2 and LHe*

			Nitrogen	Helium
Normal boiling point			77 K	4.2 K
Amount of gas (at 20°C) produced by evaporation of 1 litre of liquid at the normal boiling point			694 litres	750 litres
Molecular weight			28	4
Density of liquid at normal boiling point (kg/m^3)			810	125
Colour:	of liquid		Colourless	Colourless
	of gas		Colourless	Colourless
Odour (of gas)			None	None
Toxicity (in normal laboratory conditions)			None	None
Fire hazard		- flammable	No	No
		- promoting ignition	No	No
		- causing oxygen enrichment	Yes	Yes
Explosion hazard (with combustible materials)			None	None

7.3. *Description of the hazards*

7.3.1. *Extreme cold - background information*

Any part of the body which comes into contact with extreme cold could suffer injury. Small splashes of liquid nitrogen may not burn skin because, as the liquid boils, an insulating layer of vapour is formed, but even small splashes can burn your eyes badly. Jets of cold gas or liquid are almost certain to cause severe cold burns, and they are potentially more dangerous than cold surfaces.

A cold burn is very similar to a burn caused by heat. The amount of damage caused depends on the temperature and the duration of exposure. Delicate tissues (like eyes) are affected much more easily and quickly than hard skin. The effect of a cold burn is not obvious as quickly as a heat burn, and it may not hurt immediately.

7.3.2. Explosion - background information

The temperature of any liquid in equilibrium with its own vapour varies with pressure. If the pressure is kept constant, the liquid remains at a constant temperature and the evaporation rate depends upon the amount of heat reaching the liquid. As the liquid evaporates and the gas warms up its volume rises in proportion to the temperature.

Danger If this gas is not allowed to escape from the dewar (either because of a mistake in closing a valve, or because of ice blocking the exhaust), the pressure will rise until it reaches a dangerous level. The cryostat could explode like a bomb.

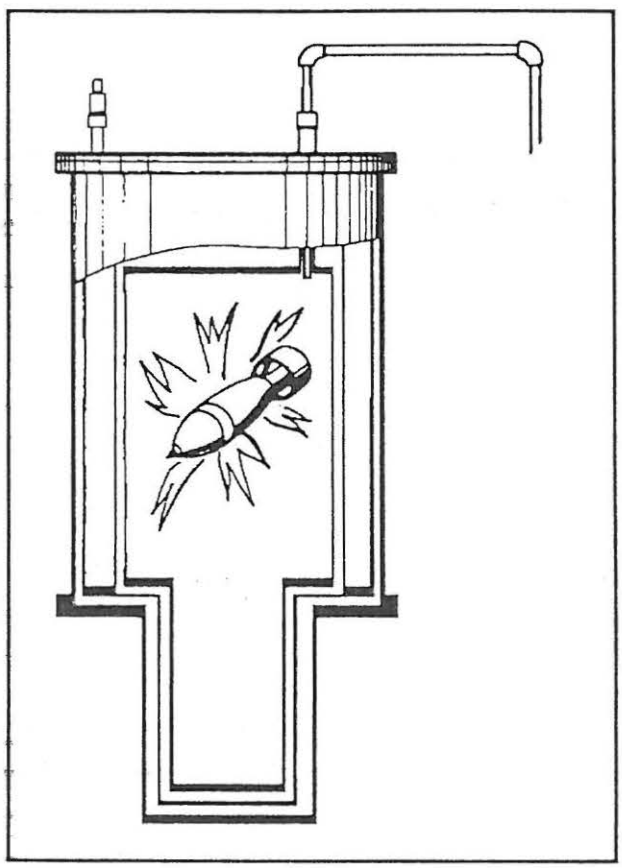


Figure 7.3.2. Beware! The cryostat could explode like a bomb if the vents are not kept clear.

The normal flow of cold gas usually helps to cool the vent tube, so the heat load and boil off may be increased when a tube becomes blocked. The pressure can then rise even more quickly than you expect.

8. *High magnetic fields and their effects*

This background information supplements the specific recommendations earlier in the booklet.

8.1. *Large attractive forces - background information*

Hazard Magnetic materials in a magnetic field experience a force which increases very quickly as they approach the magnet. By the time you feel the force it may be too late, and a magnetic item may be pulled uncontrollably towards the magnet.

Small items may damage the cryostat, particularly if parts of it are very delicate. It is possible for hand tools to dent or even rupture metal vacuum vessels, causing touches between the room temperature components and the cold parts, or loss of insulating vacuum. Cryostats which are fitted with windows are even more vulnerable, and you should fit guards around the windows, so that the beam line is not obscured but so that most items will be caught by the guards.

Danger Larger magnetic objects are even more dangerous. For example high pressure gas bottles are almost always made of steel and they are highly magnetic. Other pieces of equipment commonly used in the laboratory (such as vacuum pumps and electronics racks) are also magnetic. If one of these items starts to move towards a magnet, it is very unlikely that you will be able to stop it. Let go rather than risk being trapped. If you are trapped between one of these large items and the magnet you may be severely injured or even killed.

Warning **Keep magnetic items away from the cryostat.** Even if large magnetic items are fixed well enough to prevent them from moving, they can distort the field so much that the magnet quenches. It is difficult to predict the effects without complex computer modelling techniques so the safest approach is to keep magnetic items well away from the system.

8.2. *Effects on other equipment - background information*

Hazard Other equipment may be directly affected by the presence of large magnetic fields. The field may cause permanent damage, or it may only have a temporary effect until the field is removed. The following guidelines give typical examples.

Some equipment may be affected by fields as low as 1 gauss. Examples include image intensifiers, photomultiplier tubes, electron microscopes and accurate measuring scales.

Public access to areas where the field is greater than 5 gauss should be restricted and warning signs erected. Medical implants, motor vehicles and cathode ray tubes may be affected by fields at this level.

Watches, tape recorders and cameras may be magnetised and irreparably damaged if exposed to fields above 10 gauss. Information encoded magnetically on credit cards and magnetic tape or computer floppy discs may be irreversibly corrupted. The image on visual display units (such as computer screens) may be distorted or the colours may be changed. Electrical transformers may become magnetically saturated in fields above 50 gauss. The safety characteristics of equipment may also be affected.

8.3. Medical implants

Danger

Erect suitable notices to warn visitors, and make sure that none of your staff are vulnerable. The operation of medical electronic implants, such as cardiac pacemakers, may be affected either by static or changing magnetic fields. Pacemakers do not all respond in the same way or at the same field level. You may not know that one of your visitors has a pacemaker, so it is important to erect suitable signs to warn them of the danger. The stray fields caused by your magnet in other surrounding rooms may be enough to affect them.

Other medical implants, such as aneurysm clips, surgical clips or prostheses, may contain ferromagnetic materials. Therefore they may experience strong forces near the magnet which could result in injury or death. Rapidly changing fields (e.g. pulsed gradient fields), may induce eddy currents in any metallic implant, even if it is not magnetic, and generate heat.

8.4. Electrical properties of superconducting magnets

Superconducting magnets usually have high inductance and operate at high currents. A large amount of energy is therefore stored in the magnet when it is at field.

$$\textit{Stored energy} = \frac{1}{2} L I^2$$

where L is the inductance of the magnet and I is the current in the magnet. For a high field laboratory magnet this stored energy can typically be 2 mega Joules or more. This is the amount of potential energy stored in a 1 tonne mass at an altitude of 200 m!

Since most magnets have a high inductance, it is also possible to generate very high voltages if you attempt to change the current very quickly.

$$\textit{Induced voltage} = -L\frac{dI}{dt}$$

If a magnet quenches, it is not uncommon for the current to decay at 100 As^{-1}, so it is possible to generate voltages of tens of kilovolts unless the magnet is suitably protected.

9. *Poisons and hazardous substances*

Some special systems contain materials which are poisonous or hazardous in other ways. All of the hazardous materials supplied by Oxford Instruments can be handled safely if the recommended procedures are followed carefully.

9.1. *COSHH information*

Hazardous materials will be supplied with suitable documentation to warn you about the potential hazards. The (British) Control Of Substances Hazardous to Health (COSHH) regulations require that this information is easily available to anyone working with these materials, and the "COSHH form" for a material is often the best way to give you this information. In particular, some window materials are poisonous.

9.2. *Handling procedures for radioactive ^{60}Co sources*

Low activity ^{60}Co gamma ray sources are sometimes used as thermometers on dilution refrigerator systems working at temperatures below 100 mK. They normally have activity < 5 micro-curies but they must be handled carefully. The procedure for mounting the source in the cryostat must be carried out as quickly as possible.

- keep the source in container/safe box until required
- handle the source with tweezers. Avoid direct contact with the radiation source
- do not stare directly at the source
- do not leave source unattended without identification
- wash your hands thoroughly immediately after working with the source

9.2.1. *Mounting ^{60}Co crystals*

Warning Ensure that the surface on which the crystal is to be mounted is flat and 'tinned' with Wood's metal. Use a soldering iron to tin the crystal with Wood's metal. Do not allow the crystal to be heated above 300°C at any time. Place the crystal on the holder and press it down with a suitable piece of stainless steel to ensure that the crystal is flat on the holder surface. Do not use a naked flame in the vicinity of the crystal. Wash your hands, and any tools used to touch the crystal. Avoid all direct contact with the crystal.

9.2.2. *Removal of ^{60}Co crystals*

Remove the crystal from its holder and immediately place it in the container. Do not touch the crystal - use tweezers at all times. Wash your hands and clean all tools used to touch the crystal.

9.2.3. *Registration of source*

If you have bought a radioactive ^{60}Co source, local regulations may require you to register the source under either Health and Safety regulations or Radioactive Substances controls.

Assembling the system

Contents

Commissioning requirements for the system.

The following documents describe how to assemble the system.

Unpacking the system

The system should be unpacked carefully and inspected for any damage which may have been caused during shipment from Oxford. It should also be checked to ensure that none of the components are missing. If any problems are encountered you should contact *Oxford Instruments* (through our agent or subsidiary if appropriate).

The dewar may be fitted with a "packing bung" to prevent movement of the inner parts during shipment. If so, it will have a label on the outside to warn you, and to explain what has to be done to remove it.

Commissioning requirements for cryogenic systems

If you are planning to install a laboratory scale cryogenic system you are likely to need most of the following equipment. Some of it may be supplied with the system; other items may only be needed occasionally. If your system contains a superconducting magnet, ^{3}He refrigerator or dilution refrigerator there are additional requirements, and these are listed separately.

Safety equipment

- personnel protection equipment including gloves and goggles
- hazard warning signs to make sure that anyone approaching the system is aware of the potential hazards

Tools

- spanners or wrenches (open ended metric set). 5 to 19 mm
- Allen keys (metric set) 1.5 to 12 mm
- screw drivers, pliers, side cutters etc.
- hot air gun
- electrical soldering iron
- digital multimeter (with low current ohms range).

Lifting equipment

- suitable method of lifting the system from the delivery vehicle
- suitable hoist or crane for use in the laboratory
- lifting sling and shackles to suit the lifting points on the system

If you do not have access to lifting equipment above the position where you run the system you can use a trolley to transport the system to the hoist. It may be necessary to remove the system from the trolley when you are running it.

Vacuum equipment

- high vacuum pumping system to evacuate the insulating vacuum spaces, including a diffusion or turbomolecular pump and a liquid nitrogen cooled trap, flexible metal pumping lines for connection to the cryostat and a two stage backing pump. It should be capable of reaching a pressure of 10^{-6} mbar.
- a mass spectrometer leak detector system is required sometimes, especially when the system is commissioned, for routine leak testing operations.
- oil mist filters fitted to all rotary pump exhausts.
- a range of vacuum fittings (ISO KF fittings (also known as NW or DN) are used as standard)

Cryogens and gas supplies

- liquid nitrogen in a self pressurising dewar
- liquid helium
- a supply of recovery grade helium gas with a regulator, at a pressure variable between 0 and approximately 1 bar gauge.

Consumables

- roll of mylar adhesive tape
- roll of aluminium adhesive tape
- tube of vacuum grease
- pair of cotton gloves for handling clean items
- 'Scotchbrite' or equivalent mild abrasive for polishing or removing old indium wire from joint faces.
- metal polish and degreasing agent or solvent for general cleaning.
- indium wire (1mm diameter)
- rubber soccer ball bladders (2 needed).
- assorted latex rubber and polythene tubing
- fishing line or dental floss

Other equipment

- helium transfer tube (or 'siphon')
- level meters for cryogen reservoirs (if required) or a suitable 'dipstick'
- suitable gas flow meters may be useful sometimes

Variable temperature inserts

- single stage rotary pump with a displacement of at least 18 m^3/hour and capable of reaching a pressure below 1 mbar (with a pumping speed of at least 15 m^3/hour at 1 mbar).

Power supply

If your system requires a large amount of power follow the recommendations in "Typical power requirements of components supplied with Oxford Instruments systems".

Additional requirements for superconducting magnet systems

In addition to the items listed in "Commissioning requirements for cryogenic systems", superconducting magnet systems typically have the following requirements.

- additional hazard warning signs, barriers or controlled entry systems appropriate for magnet systems
- a suitable power supply for the magnet and superconducting switch.
- if you have a helium recovery system in your laboratory it should be capable of handling (or safely releasing) the large amount of gas generated in the event of a quench.

If there are magnetic items in the floor (for example reinforcement in concrete floors)

- wooden or non-magnetic platform strong enough to support the system. It should typically be 25 cm high.

Additional equipment needed for systems with lambda point refrigerators

A suitable single stage rotary pump or Leybold Sogevac pump with a displacement of 40m^3/hour or greater, (and preferably 60-80 m^3/hour for larger systems) with a connecting line from the pump to the cryostat, a valve to shut off the pump and a gauge for the pressure range from 0 to 100 mbar. An oil mist filter and a suitable exhaust line are also required, especially if you are connecting it to a helium recovery system.

Assembling magnets and support systems

The magnet hangs from the magnet support system which includes the protection circuit and the other services required for the magnet. The general assembly drawing of the system shows how the system fits together.

Remove the magnet from the packing case. Suspend the magnet support system from a suitable hoist. Slowly lower it onto the magnet so that the fixings in the top of the magnet fit through the holes in the support plate. Choose the orientation of the magnet to suit any mechanical alignment requirements (for example if the blow out tube has to fit into a slot), or so that the multi-pin connector for the protection circuit and the main current leads can be connected.

Adjust the bolts which hold the magnet to the support system so that the magnet hangs vertically. There is a line around the outer case of the magnet to show the position of the field centre. Set this at the correct height with respect to the top flange of the magnet support system by referring to the drawing of the system.

Connect the multi-pin connector on the support system to the magnet and secure the connector with bolts or by tying it with a suitable insulating material. Connect the magnet current leads by soldering the flying leads from the support system to the terminals (or flying leads) on the magnet. The soldered joint should be over the whole tinned length of the terminal, (or 30mm on flying leads). The joint should be securely bound together with wire before it is soldered. Insulate the joint with suitable sleeving.

Warning **Never attempt to run the magnet without the protection circuit connected. Do not attempt to modify the protection circuit in any way. It was designed for your magnet. This is essential for your safety and to protect the system from damage.**

If your system has a siphon cone, fit it to the magnet support system as shown on the general assembly drawing. Make sure that the extension tube is the correct length to reach the bottom of the helium reservoir and cut it at an angle so that it cannot be blocked easily by the base flange of the reservoir. If you have bought a complete system this will have been done in the factory.

If your system is fitted with a variable temperature insert (or any other insert) fit it into the magnet support system to make sure that the magnet is in the correct position and that none of the wiring will be damaged. Mylar or Kapton film should be taped around the tail of the insert as electrical insulation.

Check all connections for electrical continuity and isolation from ground (to at least 10 MΩ). If possible, load the magnet support system and insert into the dewar together and secure them in place. However, if the insert is designed to be loaded into the system while it is cold (for example Kelvinox inserts fitted with a 'sliding seal') you may prefer to remove it before loading the magnet support system into the dewar.

Assembling liquid nitrogen shielded dewars

Some liquid nitrogen shielded dewars are shipped from the factory with the outer vacuum chamber (OVC) under vacuum. The labels on the outside of the dewar will explain whether any packing has to be removed, and whether the OVC is under vacuum. If there is any packing inside the OVC you should remove it by taking out the ring of bolts which holds the OVC tube to the top plate. Any packing will be painted red, and it should be removed before the dewar is used. There may also be some packing in the neck of the dewar, to support it in transport

If possible the OVC should be kept under vacuum at all times. This helps to keep the superinsulation clean and so the boil off of the dewar is minimised.

Caution **Avoid venting the vacuum in the OVC if possible. If you have to vent the OVC take the following precautions:**

- **only vent the OVC when the dewar is completely warm**
- **make sure that the helium reservoir has already been vented to atmospheric pressure**
- **vent it very slowly to avoid any risk of collapsing the helium reservoir or moving the superinsulation.**

If you do have to remove the OVC make sure that you do not allow the superinsulation to become dirty. Avoid touching it with your bare hands, because grease and finger marks may affect the performance of the system. Clean all 'O' rings and check them for damage. Lightly grease them before you re-assemble the dewar.

If the cryostat is already under vacuum and you want to check the pressure in the outer vacuum chamber you can do so as follows. Pump the line up to the OVC valve with a diffusion pump (or turbo-molecular pump). Close off the diffusion pump and open the OVC valve. Read the pressure on a pressure gauge connected to the pumping line. If the OVC needs to be pumped you can now decide whether or not the pressure is too high for the diffusion pump. If so pump it with the rotary pump until the pressure is low enough.

Before you use the dewar you should pump the OVC to high vacuum using a diffusion or turbomolecular pump system (fitted with a cold trap to collect condensable vapours). Even if the OVC has been left under vacuum since the last run the surfaces inside the OVC are likely to outgas, and the vacuum will not be sufficiently high. There may be a sorb in the OVC to help to maintain the vacuum while the system is cold, and pumping the OVC whenever the system is warm helps to keep it clean. If possible you should pump the OVC overnight (or longer), until the pressure at the pump drops to $< 10^{-4}$ mbar.

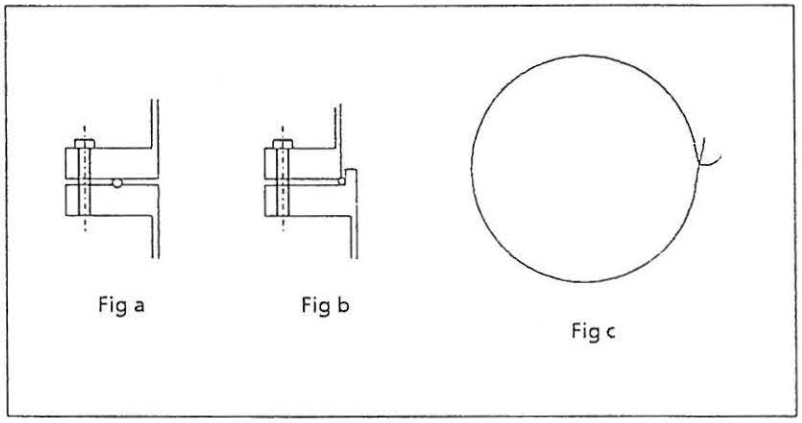
You can assemble the other parts of the system into the dewar while you are evacuating the OVC.

Making indium seals

Oxford Instruments uses two main types of indium seal, as illustrated in the diagram below. They both use 1mm diameter wire, retained

- either in a groove by a flat surface
- or in a corner between two flanges

In both cases, the indium wire is overlapped by bending one end of the wire sharply outwards and laying the other end across the corner of the bend. The wire is so soft that the joint will be compressed into a cold weld.



Indium seals

Preparations

Before you make the seal ensure that the groove and the mating surfaces are clean. Thoroughly remove any old indium wire from the seal faces. If necessary a solvent can be used for cleaning. Some people like to grease the metal surfaces with silicone vacuum grease to make it easier to remove the wire later, but this is not necessary.

Making the seal

Lay a new piece of indium wire in the groove or round the male spigot on one of the flanges and overlap it as shown on the diagram. There are usually alignment marks on the flanges to indicate the correct orientation. Carefully bring the two flanges together and hold them loosely in place with two bolts while you put the other bolts into the flanges and tighten them by finger only. Slowly and evenly tighten all of the bolts with a small spanner (wrench) or Allen key. Do not tighten them too much. There is no need to use an extension on the tool to give extra leverage. On large seals (typically > 50mm diameter) it is then best to leave them for about an hour. The indium flows slightly during this period so it is often possible to tighten the bolts slightly more.

Separating indium seal flanges

It is often difficult to separate indium seal flanges because the indium metal seems to glue them together. Most large indium seals made by *Oxford Instruments* have two or more threaded holes in one of the flanges for 'jacking screws'.

Remove the bolts that hold the indium seal together and use two of these bolts to jack the flanges apart by screwing the evenly into the jacking screw holes from the same side of the flange. This will push the flanges apart.

If there are no jacking screw holes (as often happens on small diameter indium seals), the flanges can be separated by inserting a sharp blade between the flanges. Make sure that the blade does not slip and cut you as the flanges separate.

Pre-cooling the system

Contents

This section describes how to prepare the system for precooling. You should read all of it before you attempt to pre-cool the system.

When you have prepared the whole system for precooling, follow the instructions in the following document to cool the system to 77K.

Preparing a Nb_3Sn magnet for pre-cooling

Electrical checks

When the magnet and magnet support system have been loaded into the dewar as described in the assembly section you should check the wiring carefully using a multi-meter. Make sure that the resistance between all pins on the electrical connectors is as expected. The magnet windings should be electrically insulated from all the other wiring to greater than 1MΩ. Check the following:

- magnet to switch heater
- magnet to dewar (ground)
- magnet to all other diagnostic wiring

Caution **Your magnet contains coils made from the brittle intermetallic compound Nb_3Sn. This material is fragile and it should not be subjected to thermal shock, so you should cool it slowly as described below. It is typically used for magnets specified to reach a field above 9T at 4.2K or 11T at 2.2K.**

Slow pre-cool for Nb_3Sn magnets

The pre-cooling rate can be reduced by limiting the flow of liquid nitrogen into the helium reservoir. The simplest way to do this is to restrict the size of the exhaust line and the pressure in the liquid nitrogen storage dewar.

Fit a restriction to the helium reservoir exhaust port. This should have an inner diameter of approximately 6mm, and you should fit a 300mm length of rubber tube to this. Set the pressure in the liquid nitrogen storage dewar at approximately 250mbar before you start to pre-cool the system.

Preparing liquid nitrogen shielded dewars for pre-cooling

Evacuating the OVC

Evacuate the outer vacuum chamber (OVC) of the dewar. It may be under vacuum already. If you want the optimum boil off performance it is important to pump the OVC with a high vacuum pump, not just a rotary pump. A 50 mm (or larger) diffusion pump fitted with a cold trap to collect condensable vapours is best because it pumps all gases well, (including helium). A turbomolecular pump with a cold trap (and backed by a two stage rotary pump) can be used but if there is any helium in the vacuum space it will take a long time to pump it away because these pumps have a low compression ratio for light molecules. Always use pumping lines which are at least 25 mm diameter and as short as possible. Do not use lines which have previously been used to carry helium gas. A suitable liquid nitrogen cooled sorption pump could also be used, but this would not pump helium gas at all.

It is possible to cool the system down without pumping the OVC with a diffusion pump but the system boil off is likely to be increased. We recommend that you always pump the OVC to a high vacuum before you cool down the system.

Load the other parts of the system into the helium reservoir of the dewar as shown in the general assembly drawing of the system.

Pumping and flushing the helium reservoir

This operation is typically part of the leak testing procedure for other parts of the system, so refer to the other sections describing how to prepare the system before carrying it out. Otherwise it is only necessary to pump and flush the helium reservoir if other parts of the system have to have all of the air purged from them (for example to prevent possible blockages).

Warning Do not pump on the main helium bath unless the OVC is already under vacuum.

Disconnect the recovery system from the cryostat. Connect a rotary pump to the exhaust of the helium reservoir and pump it to a rough vacuum (typically 1 mbar) to remove the air and moisture. Fill the helium reservoir with helium gas. If you want to check that there are no leaks from the helium reservoir to the OVC before you pre-cool the system you can do it as you vent it with helium gas.

Precautions to be taken before pre-cooling

- fill the liquid helium vessel with liquid nitrogen before pre-cooling the liquid nitrogen jacket
- make sure that at least one port on the liquid nitrogen jacket is fitted with a non-return valve

Pre-cooling the system

Make sure that you have carried out the preparations described for each part of the system before you start to pre-cool it. These are described in the other pages of this section of the manual.

Warning "*Elementary Practical Cryogenics*" gives some background information about transferring liquid nitrogen. Refer to it if you are unsure of the correct procedures. It is also important to be aware of the correct safety procedures, as described in the booklet "*Safety Matters*" which is included in the Safety section of this manual.

Disconnect the main helium bath from the helium recovery line (if you have one in your laboratory). Some systems have to be pre-cooled slowly to make sure that they are not damaged by thermal shock. If so, precautions are given in the description of the preparations that you should carry out before pre-cooling the system. Insert the liquid nitrogen "blow out tube" through the siphon port. If there is a siphon cone on the IVC or magnet support system it is best to push the blow out tube into it (or screw it in if there is a thread on the end of the tube) but it is not essential. Connect a suitable tube from the top of the blow out tube to a liquid nitrogen storage dewar and transfer liquid nitrogen into the main bath. Fill the main bath with liquid nitrogen and leave the cryostat to pre-cool. It may take several hours to pre-cool the system, depending on the type of system. This can conveniently be performed overnight. Vapour shielded cryostats need to be pre-cooled thoroughly, to cool the radiation shields properly.

Always wait until the liquid nitrogen has stopped boiling violently.

Caution: The OVC can be pumped during the pre-cooling procedure, but we advise that it should be isolated from the pump before the helium transfer is started.

Cooling the system to 4.2 K

Contents

This section describes how to blow out the liquid nitrogen, carry out leak tests at 77K and prepare the system for cooling to 4.2 K. You should read all pages of this section before you attempt to transfer liquid helium.

When you have prepared the whole system for the liquid helium transfer follow the instructions in the following document to cool the system to 4.2 K.

Preparing liquid nitrogen shielded dewars for cooling to 4.2 K

The system should now be at 77 K and full of liquid nitrogen.

Leak testing the OVC

If you want to check that there are no leaks from the liquid helium reservoir to the OVC you can do this by observing the helium signal in the OVC while the helium reservoir is filled with helium gas. Most cold leaks can be detected at 77 K, so there is little risk of a leak developing as the system is cooled to 4.2 K. However, if you have used the system without problems for a few weeks you may feel confident enough to run it without further testing. Close the OVC valve after you have completed the leak tests.

Blowing out the liquid nitrogen

Blow out the liquid nitrogen as described in "Blowing out the liquid nitrogen". You can use this liquid to fill the liquid nitrogen jacket of the dewar. The helium reservoir should then be pumped and flushed with helium gas.

Filling the liquid nitrogen jacket

Fill the liquid nitrogen jacket with liquid nitrogen until it overflows.

Preparing for the liquid helium transfer

Fit a non-return valve to at least one of the liquid nitrogen jacket ports, and either non-return valves or Bunsen valves to the other ports. This will ensure that air is not condensed into the tubes during the liquid helium transfer, causing dangerous blockages.

Blowing out the liquid nitrogen

Insert the liquid nitrogen blow out tube into the siphon port. If there is a siphon cone on your system push the blow out tube into it, and if there is a thread on the blow out tube screw it into the siphon cone. Connect the top of this tube to one of the nitrogen jacket ports on your dewar, or if you have a vapour shielded dewar connect it to a suitable storage dewar. Blow the liquid nitrogen out of the main bath using a slight overpressure of helium gas supplied through the exhaust port. 200 mbar should be sufficient. When all the liquid nitrogen has been removed (which can be seen by observing the pressure drop in the main bath) withdraw the blow out tube and insert the bung in the siphon port. Re-connect the main bath recovery line.

Pumping and flushing the helium reservoir

Pump and flush the helium reservoir of your system to carry out leak tests or to make sure that the liquid nitrogen has been removed completely. Complex systems with small capillary tubes could be blocked or superconducting magnets may be affected by frozen nitrogen.

If you are planning to test the system for leaks you can do many of the tests while you pump and flush the helium reservoir. Read the leak testing section for all the other parts of the system before you carry out the procedure.

Pump out the helium bath using the auxiliary pump, to ensure that no liquid is left. The pressure should fall steadily to about 1 mbar. If this does not happen (for example, the pressure hesitates at 100 mbar) it indicates that the liquid has not all been removed. Vent the main bath to one bar with helium gas, make sure that the blow out tube reaches the bottom of the helium reservoir, and try again to blow out any remaining liquid.

Cooling systems to 4.2 K

Liquid helium has a very low latent heat of evaporation but the gas has high enthalpy. This means that it is very easy to evaporate the liquid but it is difficult to warm up the gas so produced. Liquid helium therefore has to be transferred very carefully. If you do not transfer it properly you may lose all the liquid from your storage dewar without collecting any in your system. Follow these instructions to get an efficient liquid helium transfer.

When you are cooling down a system to 4.2 K it is very important to transfer the liquid helium to the lowest point in the helium reservoir. If the system is warmer than 4.2 K the liquid boils almost immediately as it leaves the vacuum insulated transfer tube (or siphon). Very little cooling is obtained from this evaporation. However, this gas then has to pass over the equipment in the helium reservoir to reach the exhaust line, and this provides very useful cooling power. If you transfer the liquid helium into the system slowly you can make sure that the gas emerging from the exhaust line is not too cold. This ensures that you do not waste any cooling power. If you do transfer the liquid too quickly you may see liquid air running from the recovery line, indicating that the cooling power is being wasted.

Preparations for the helium transfer

Check that the leg lengths of the transfer tube are suitable. The storage dewar leg should be able to reach below the liquid level (and preferably reach the bottom of the dewar). The system leg should be able to reach the lowest point in the helium reservoir (or the siphon cone if one is fitted). Position the liquid helium storage vessel so that the transfer tube can be easily inserted to both the storage dewar and the system, and blow some helium gas through the transfer tube to remove the air.

If you have a helium recovery system, connect the exhaust line of the system's helium reservoir and the storage dewar to it. If you do not have a recovery system, make sure that the exhaust is free to vent but that there is no risk that the system will be filled with air condensed from the atmosphere. You can do this by connecting a flexible line a few meters long to the exhaust port. Let the other end lie on the floor. The helium in this line is lighter than air and tends to prevent air from rising to the exhaust port. However, when the helium transfer is complete, or if the system is to be left open to air for more than a few minutes, you should put a one way valve on the cryostat exhaust port.

Close the OVC valve on the cryostat. There is no need to continue to pump it.

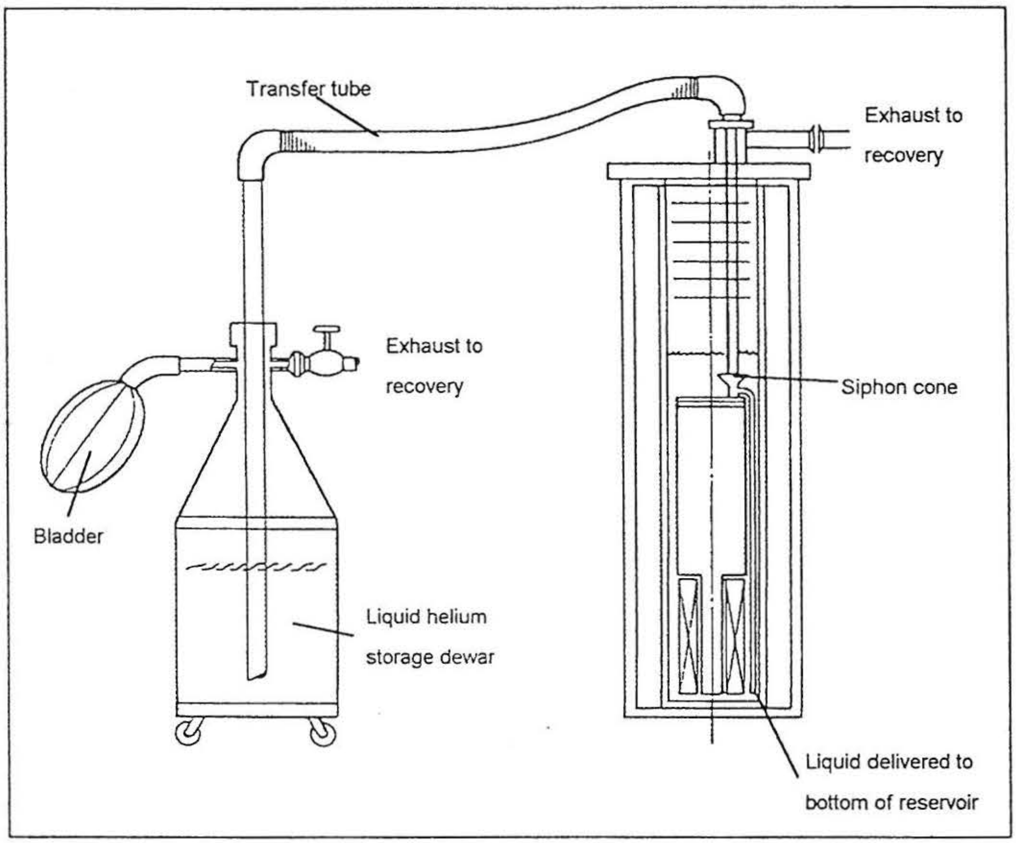
Transferring liquid helium

Remove the plugs from the system's transfer tube entry port and the top of the storage vessel. Insert the transfer tube legs into the system and into the storage dewar slowly, allowing the dewar leg to cool gradually. Make sure that the end of the transfer tube in the cryostat reaches the bottom of the helium reservoir (or the siphon cone if fitted).

Close the exhaust line on the storage dewar and pressurise it slightly to start the liquid transfer. (This is generally done by gently squeezing a rubber bladder). The transfer rate should be such that the vent pipe is frozen for not more than 2 m (6 ft.) of its length. The initial transfer rate should be equivalent to between 4 and 10 litres of liquid per hour.

When liquid starts to collect in the helium reservoir the exhaust gas flow rate will be seen to drop noticeably (as the ice on the recovery line starts to melt). The pressure on the storage dewar can then be increased to transfer the liquid more quickly.

When the liquid helium reservoir has been filled, stop the transfer by releasing the pressure in the storage vessel. Remove the transfer tube and replace the bungs.



Schematic diagram of the method of transferring liquid helium (in laboratory scale cryostats).

The booklet 'Elementary Practical Cryogenics' contains a list of solutions to the problems commonly encountered in liquid helium transfers. Refer to this booklet if you are having problems.

Running the system

Contents

The following documents describe how to run the system assuming that it has been successfully cooled to 4.2 K.

Running the magnet at 4.2K

Introduction

Many different types of power supply are available to run the magnet. The magnetic field is proportional to the current supplied to the magnet. The voltage available from the power supply determines the maximum sweep rate.

The current range of *Oxford Instruments* superconducting magnet power supplies (including the IPS120-10 and PS120-3) work in 'current control mode' with a voltage trip. This means that if the power supply's output voltage reaches the hardware voltage limit the power supply will trip and go into the HOLD state. The current will be kept constant in this state.

You can set a sweep rate limit in software to suit the maximum allowable sweep rate for the magnet or to prevent the output voltage reaching the hardware limit during normal operation. If the power supply reaches this limit it will reduce the sweep rate accordingly and a 'limiting' warning light will come on to indicate that the magnet is not sweeping at the set rate.

Older power supplies or those from other manufacturers work in different modes and a brief description of operation in 'voltage mode' is given later.

A magnet power supply is typically used to carry out the following operations:

- to supply power to the superconducting switch heater to open the switch
- to energise the magnet to the required field (or current) and hold it there
- to sweep the magnet to a set field at a defined rate
- to put the magnet into persistent mode if a constant field is required (so that the power supply can be switched off)
- to change the field direction by reversing the polarity of the current (not applicable to PS120-3)
- to run a programmed series of sweeps and holds

Power supplies can be run manually or under computer control. *Oxford Instruments* can supply software packages which are used to program the system. ObjectBench allows you to carry out a sequence of operations, so that experimental results can be taken automatically. Alternatively, Teslatron software provides a simplified user interface for the system through National Instruments LabView®, and you can write sequences of operations for the whole system and experimental apparatus.

Some magnets can be run to higher fields if they are cooled to 2.2K. They are usually cooled to this temperature by a lambda point refrigerator (or by pumping the whole helium reservoir with a rotary pump). If your magnet is not specified to run to higher currents at 2.2K do not attempt to energise it above the 4.2K field. If you do this you could cause permanent mechanical damage to the magnet.

Checking the system before operation

Before you run the magnet you should make the following electrical checks. Compare resistance values with the quoted values in the wiring section of the manual. Isolation values should typically be >1 MΩ unless otherwise stated.

- magnet resistance
- magnet to cryostat isolation
- switch heater resistance
- switch heater to cryostat isolation
- magnet to switch heater isolation

Preparing to run the magnet

If you have bought a magnet and power supply together these instructions briefly explain how to run them. However, if you are planning to run a new magnet on an older type of power supply you may have to use another mode of operation (as described later). These instructions cover the basic principles of running the magnet. If you need to find other information refer to the manual supplied with the magnet power supply.

Most magnets are fitted with a superconducting switch. If a switch is fitted to the magnet the liquid helium consumption during a field sweep is increased slightly, because of the dissipation in the switch heater and resistive heating in the switch. However, if you plan to leave the magnet at a constant field for a long time the helium consumption is greatly reduced by putting the magnet into persistent mode.

If there is no switch on your magnet just ignore the steps that refer to the switch in the following text. This is an advantage if you only want to sweep the magnet continuously and do not want to leave it at a fixed field for long periods.

Ground the cryostat effectively so that it cannot accidentally reach a dangerously high voltage in the event of a failure in the insulation if the magnet quenches. Before you connect the power supply to the electricity supply, connect the magnet current leads and the superconducting switch heater lead to the terminals on the back of the power supply.

Warning **Before you run the magnet make sure that you have taken the necessary steps to ensure your own safety and the safety of other people working around you. Refer to the booklet "Safety Matters", which is included in the Safety section of this manual.**

Connect the leads to the cryostat magnet terminals and fit the rubber boot over the connector. Connect the switch heater lead to the appropriate ten pin connector. Switch on the magnet power supply.

Warning **Do not disconnect the power supply from the magnet while it is at field unless your system is fitted with special demountable current leads. You may be putting your life at risk.**

Energising the magnet from zero field

The power supply will initialise by displaying the software version, then zero. The output is 'clamped' when the power supply is first switched on. Press the HOLD button to unclamp it and put the power supply into HOLD mode.

Make sure that there is sufficient liquid helium in the system to ensure that the magnet is still covered with liquid at the end of the field sweep.

Select the display mode that you require (in amps or tesla) by pressing the button labelled CURRENT/FIELD. The relationship between the current and field for your magnet and the appropriate sweep rates can be set in software. If you bought the power supply with the magnet this should have been set up in the factory and does not need to be adjusted. However, some magnets have to be run at slower sweep rates the first time they are energised after cooldown or after transport. See the test results for details.

You can set the power supply to run the magnet either to a 'set field' or to a 'set current' depending on the display mode that you chose earlier. Press and hold the SET POINT button and use the RAISE and LOWER buttons on the ADJUST panel to select the set point. You can set the 'sweep rate' in a similar way by pressing and holding the SET RATE button and using RAISE and LOWER. On IPS120-10 power supplies you can also choose the polarity of the current supplied to the magnet, and thus the direction of the field.

Caution The current for maximum field and the recommended maximum sweep rates for your magnet are given in the magnet data sheet supplied in the test results section of this manual.

You can change the SET RATE while the magnet is being energised (if necessary), so you can choose the SET POINT to be the value that you want to reach at the end of the sweep (not at the point where the sweep rate changes). You can also set sweep rate limits for the power supply (for different current ranges) so that the sweep rate changes automatically as the magnet sweeps.

If the magnet is equipped with a superconducting switch, press the HEATER ON button (on the SWITCH HEATER panel). The power supply makes several checks to ensure that it is safe to run the magnet and if it finds no problems the switch heater light is illuminated straight away.

If it finds a problem the light will not come on. Check that everything is properly connected and that there is no reason not to energise the switch. Typical problems include:

- the power supply thinks that the magnet is already at field
- the switch heater is not connected properly

If you decide to override the power supply's checks, press and hold the HEATER ON button for about five seconds until the indicator light comes on. Wait for 15 seconds to make sure that the switch is open.

Start to energise the magnet by pressing the GOTO SET button (or the SET POINT button on PS120-3 power supplies) on the SWEEP CONTROL panel. The current or field will start to change on the digital display. The output voltage will vary with the sweep rate, the inductance of the magnet, and the resistive voltage drop in the current leads.

When the power supply reaches the set point wait until the output voltage reaches a steady value. If your protection circuit is of the resistor/diode type this will happen quickly. Resistor protection circuits have a longer time constant and it may be necessary to wait for a minute or longer.

Establishing persistent mode

Turn off the switch heater by pressing the HEATER ON button again. Wait for about 60 seconds for the switch to become superconducting. Press the ZERO button on the SWEEP CONTROL panel. The current in the magnet leads will decrease to zero leaving the magnet in persistent mode. The leads can be swept faster than the magnet, and the power supply software automatically runs the leads up or down at a higher rate (typically 240 amps/minute).

Taking the magnet out of persistent mode

The magnet can be taken out of persistent mode by using the following procedure. This assumes that you are using the same power supply and that none of the settings have been changed since you put the magnet into persistent mode. The power supply will remember the settings even if it has been turned off.

Press the SET POINT button on the SWEEP CONTROL panel. The current leads will be swept quickly to the Set Point value. Turn the switch heater current 'on' by pressing the HEATER ON button. The PS120-3 and IPS120-10 carry out various checks before the switch heater is turned on. Normally you will not notice this happening, and the switch heater light will light up when you release the button. Wait for about 15 seconds.

If the switch heater does not come on immediately, the power supply thinks that the current it is supplying does not match the current in the magnet. Check to make sure that you have done everything properly. If you decide that the current in the leads matches the current in the magnet, (and is in the same direction), you can override the power supply's checks. Press and hold the HEATER ON button for about five seconds until the indicator comes on.

Running the magnet to a new set point (or running it down)

If you want to run the magnet to zero field press the ZERO button on the SWEEP CONTROL panel. The magnet will start to run down at the rate defined . The sweep rate can be changed without stopping the sweep (if required).

If you want to change the field, press and hold the SET POINT button and RAISE and LOWER to change the set point to the new desired value. IPS120-10 also allows you to choose a set point of the opposite polarity. Choose the sweep rate and press the GOTO SET button (or SET POINT button on PS120-3) on the SWEEP CONTROL panel and the magnet sweeps to the new set point.

When the magnet has reached the new set point and the voltage has stabilised you can turn off the switch heater.

Running the magnet in constant voltage mode

Introduction

If you are not using one of the current range of *Oxford Instruments* power supplies you may have to run the magnet in constant voltage mode. The only advantage of this mode is that the power supply can be simpler to make. It is difficult to control the sweep rate accurately or to automate operation of the system.

The magnet is swept to a set current (or to zero) at a constant voltage, measured at the power supply terminals (or sometimes at the magnet itself using a four wire measurement technique). There are two components to the voltage that the power supply must provide:

- the resistive voltage drop in the current leads (which varies with the current)
- the induced voltage due to the inductance of the magnet (which varies with sweep rate)

If you use a four wire measurement it is possible to eliminate the resistive voltage drop from the measurement so that you can set a constant sweep rate. You can then neglect the steps taken to measure the resistive component of the voltage in the instructions that follow.

Preparation

Prepare the system as described in the Preparation section above.

Energising the magnet in constant voltage mode

With the switch heater off, sweep the power supply to the required current manually. Measure the voltage at the power supply output terminals. This is the resistive voltage drop in the magnet leads. If you want the magnet to reach the set current it is necessary to set an energisation voltage higher than this value.

Sweep the power supply back to zero amps.

Turn the superconducting switch heater on and wait for 15 seconds for the switch to open.

Turn the positive voltage setting to a value higher than the resistive voltage drop measured above. The next section describes how to choose the right voltage. The higher the voltage you set the faster the magnet will sweep to field. Do not exceed the maximum sweep rate recommended for your magnet.

Allow the power supply to sweep the magnet to field. Turn the switch heater off and wait for 30 seconds. Run down the leads manually to leave the magnet in persistent mode.

Choosing the voltage for the required sweep rate

You can calculate the induced voltage corresponding to the required sweep rate from the following equation.

$$Induced\ voltage = -L\frac{dI}{dt}$$

where dI/dt is the sweep rate in amps per second and L is the inductance of your magnet.

Neglect the negative sign from this calculation. If you want to sweep the magnet up add this value to the resistive voltage measured earlier. If you want to sweep the magnet down, subtract it from the resistive voltage.

To take the magnet out of persistent mode in constant voltage mode

Run up the leads to the set current manually. Turn the switch heater ON and wait for about 15 seconds.

Set an appropriate negative voltage for the rate at which you want to run the magnet down. Sweep the power supply back to zero amps. When the voltage has dropped to zero you can turn off the switch heater.

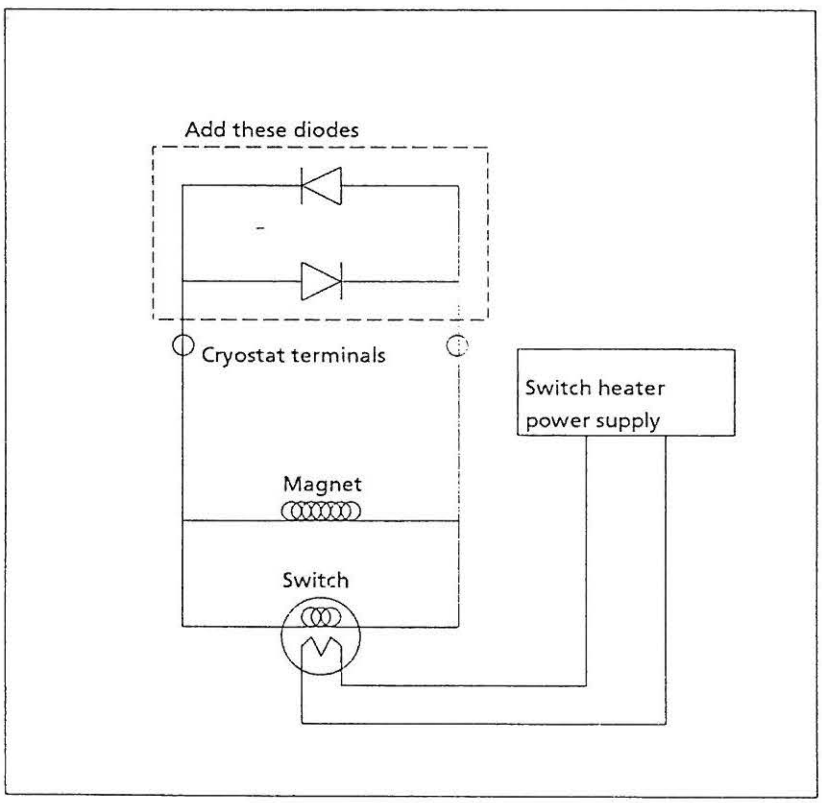
Emergency run down procedure for magnets

If it is not possible to run the magnet down conventionally using the magnet power supply it is possible to do it safely by dumping the energy into a pair of high power diodes. This might be necessary:

- if you cannot remember the polarity of the current in the magnet when it is in persistent mode
- if you cannot remember the current in the magnet when it is in persistent mode
- if no power supply is available

Warning **Never touch the current lead terminals while the magnet is at field. The protection circuit is built to prevent the development of high voltages in the event of a magnet quench, but it is not good practice to rely on it.**

Choose a pair of high power diodes capable of carrying the full operating current of the magnet and fix them to an adequate heat sink. Remember that the magnet stores a very large amount of energy so the heat sink must be well cooled. Connect a pair of diodes across the terminals as shown in the figures below. Activate the switch heater using either the power supply or a separate 6 volt battery. The switch heater current required is given in the test results section of this manual. The magnet will run down at a rate determined by the forward voltage drop of one of the diodes. The de-energisation will be slow, (for example, typically about 100 minutes using silicon diodes). Do not disconnect the diodes before the magnet is completely de-energised.



Emergency de-energisation circuit diagram

Leaving the system unattended

Running the system unattended

If you plan to leave the system to run unattended you must take the following precautions. Remember that it is your responsibility to make sure that no one is put into danger by the system. Read and learn the contents of the safety section of this manual and take appropriate actions.

- erect suitable warning signs to prevent tampering by other people
- try to make sure that only competent people have access to the system
- make sure that there are sufficient cryogens in the system
- arrange for the cryogens to be re-filled if necessary
- make sure that the exhaust lines cannot be blocked by connecting them to a recovery system or fitting appropriate one way valves
- make sure that the system can vent safely, even if it is accidentally warmed up or pumps stop running unexpectedly
- leave a telephone number so that you can be contacted in an emergency
- make sure that there is sufficient ventilation in the laboratory to avoid a potential asphyxiation hazard when you return

Leaving the system static

If you are not using the system for a few days (for example over the weekend) it is often possible to close it down and leave it in a static condition. This could save liquid helium or reduce some of the potential hazards associated with the system. To leave a typical system in static mode:

- de-energise the superconducting magnet
- close down the lambda point refrigerator and vent it safely
- close down any variable temperature insert, Heliox insert or Kelvinox insert

Re-filling the liquid helium

When the liquid helium level drops close to the minimum working level you should carefully re-fill it. When you refill the liquid helium you should take care to pre-cool the transfer tube thoroughly before you put it into the system. Otherwise the warm gas passing through the tube will evaporate liquid in the helium reservoir..

Caution **If your system contains a superconducting magnet:**

- make sure that the liquid helium level does not drop to the top of the magnet while it is energised.
- run down the magnet, if in doubt
- beware of the stray magnetic field while you are working close to the cryostat.

Pre-cooling the transfer tube (or siphon)[1]

Prepare the storage dewar and transfer tube as described in the section about "Cooling systems to 4.2K". Insert one leg of the transfer tube into the helium storage vessel, but leave the other leg outside the cryostat. Unscrew the cryostat 'siphon entry' fittings (the O-ring and the knurled nut) and slide it onto the leg of the transfer tube which will go into the cryostat. Put the bung loosely in the transfer tube entry port on the system to prevent gross contamination with air. Pressurise the transport dewar slightly, in the normal way. After about 20 seconds you should hear oscillations in the tube, gradually increasing in frequency and intensity. When these stop you should see white vapour and when liquid starts to emerge you may see a white cone (like a gas flame).

Transferring the liquid helium

Quickly release the pressure in the transport dewar and insert the open end of the transfer tube into the cryostat. If you have a transfer tube with a flexible section it is easy to do this without moving the leg in the storage dewar. However, if you have a rigid transfer tube you will have to lift it out of the storage dewar sufficiently to get the other leg into the system.

Push the transfer tube into the system to approximately the maximum helium level. Do not push it to the bottom of the helium reservoir or into the siphon cone (if there is one on your system). Quickly increase the pressure in the storage dewar again. It is most efficient to transfer the liquid quickly to reduce the losses in the transfer tube. However, 200mbar is usually sufficient pressure to so this.

The booklet "*Elementary Practical Cryogenics*" contains a list of practical solutions to the problems commonly encountered in liquid helium transfers.

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[1] This describes the easiest method of transferring liquid into a cold system for beginners. However, some laboratories have strict rules about recovering all helium gas. If you have a helium recovery system ask the administrator how to show you the preferred method of transferring helium.

Warming up the system

Contents

This section describes describe how to warm up the system safely.

Warming up the system - liquid nitrogen shielded dewars

Preparations

Before you start to warm up the system you must make sure that it is safe. The safety section of this manual gives some guidelines.

Make sure that there are no trapped volumes of liquid, gas or condensed solids inside the system. You may not know that they are there if they have accidentally been condensed into the system while it has been cold. Therefore you must make sure that all closed volumes are free to vent or that they are pumped continuously as the system warms up.

Close down any other parts of the system. In particular if your system contains any of the following items prepare them properly.

- superconducting magnets must be de-energised
- lambda point refrigerators must be closed down and pumped out (and pumped continuously during warm-up) or vented to the main helium reservoir
- variable temperature inserts, Heliox inserts or Kelvinox inserts must be closed down and vented (or pumped continuously during warm-up)

Allowing the system to warm naturally

When you have prepare the system you can leave it to warm up naturally. When the cryogens have all evaporated the system will warm slowly to room temperature. If you do not need to use it again soon this is the easiest way to warm the system up.

Warming the system quickly

If you want to warm up the system more quickly you have to blow out the cryogens and break the insulating vacuum in the outer vacuum chamber.

The liquid helium can be blown out of the system either into a storage vessel for use elsewhere or into a helium gas recovery system. Liquid nitrogen can be blown into a storage vessel or disposed of safely. The system will then begin to warm up.

If possible you should avoid warming the system more quickly than this. However, if it is essential that it is warmed up more quickly the best way is to wait for the helium reservoir and its contents to warm to above 65 K and then vent the OVC slowly with clean dry nitrogen gas. Use a volume of gas smaller than the volume of the OVC. Make sure that the OVC is free to vent safely through a non-return valve in case it contains more gas than you think.

System wiring and thermometry

Contents

The following documents describe the control and experimental wiring on the system.

Magnet support system - control wiring

Earthing the cryostat

Before you run the magnet you must make sure that the cryostat is firmly earthed using a low resistance cable. During normal operation the magnet and its protection circuit are electrically isolated from the cryostat so there is little danger of the cryostat reaching a high voltage. However, if the magnet quenches and the electrical insulation fails at any point the cryostat could reach a dangerously high voltage, causing a hazard.

Magnet current leads

Single current terminals or coaxial pairs are provided on the magnet support system for the magnet current leads. Attach the room temperature current leads to these and fit the rubber boot over the leads to make sure that you cannot accidentally touch the exposed terminals. The current leads are optimised to give the best possible electrical and thermal performance, and they are cooled by helium gas from the main reservoir of liquid helium.

Current terminal pairs are wired as follows:

Centre or red terminal = +ve = start of magnet
Outer or black terminal = -ve = end of magnet

Warnings **Do not modify the current leads on the magnet support system, and do not remove any of the electrical connectors**

Do not disconnect the power supply from the magnet while it is at field. It can help to reduce the risk of high voltages on the magnet terminals.

Magnet superconducting switch heater

The superconducting switch heater is wired to a ten pin electrical seal (usually pins 9 and 10).

Thermometers

The magnet temperature and lambda point refrigerator performance (if fitted) are generally monitored with Allen Bradley carbon resistors. An appropriate ten pin electrical seal is provided on the cryostat OVC, service neck or magnet support plate.

Specifications and test results

The specifications, special features and test results, for your system are given in the following pages TS38262.DOC

Superconducting Magnet

Performance Statement

The superconducting magnet supplied on this project was designed and manufactured as a joint development between *Oxford Instruments* and NHMFL. The original design target field was 14T at 4.2K and approximately 167 Amps operating current. In fact the conductor performance design limit of this magnet is 15T at 4.2K, however the magnet design is not limited by conductor performance alone. Stresses within the magnet windings , particularly hoop stress impose limits on the design operating field to a maximum of 14T at 4.2K (or <4.2K) based on operational experience at *Oxford Instuments* gained on a large number of high field magnets.

Extensive testing of the magnet at Oxford has shown that the magnet requires training at central field levels greater than 12T. During testing at Oxford the maximum central field achieved was 13T. All testing at Oxford was carried out with the magnet producing field in the vertical direction.

It is anticipated that future collaboration between *Oxford Instruments* and NHMFL may result in enhanced performance of this magnet to the mutual benefit of both parties, at a time to be agreed between NHMFL and *Oxford Instruments*. This work will be treated as a separate contract.

Specifications

Specifications

Guaranteed maximum central magnetic field at 4.2 K	12 tesla
Current for full 4.2 K field	143.06 amps
Field / Current ratio	0.08388 tesla/amp
Homogeneity (over 10 mm diameter spherical volume)	1 part in 10^4
Magnet clear bore diameter	150 mm
Nominal inductance	237 henries
Switch heater current for open state	220 mA
Nominal weight (see note on magnet lifting)	650 kg
Current decay in persistent mode	1 part in 10^4 per hour
Distance of magnetic field centre from base of magnet Field vertical mode	23 cm

Lifting magnet

The magnet should be lifted using the special lifting lugs provided that bolt onto the magnet former. They can be removed after the magnet is fitted to the magnet support.

Take care when resting the magnet on the floor not to damage and leads coming from inside the magnet. Damage to these leads could indirectly damage the magnet windings. Spacers should be fitted to prevent damage.

Energisation rates -

Energisation Current (A) From	To	Energisation Rate (amps/minute)	(tesla/minute)	Temperature
0	100	3	.251	≤ 4.2 K
100	130	2	.167	≤ 4.2 K
130	140	1	.083	≤ 4.2 K
140	143.06	0.5	.041	≤ 4.2 K
				Important Only at 2.2 K

The field may be swept up or down and in either direction at these rates.

Persistent mode

When setting the magnet persistent ensure the switch heater is turned off for at least 5 minutes before attempting to run down the leads. It is possible that the switch could still be resistive before this time because of the relatively large mass of the switch.

Maximum rate of change of current in the magnet leads with the magnet in persistent mode (switch heater off) — 60amps/minute

Oxford Instruments power supplies have a default rate of 240 amps/minute

Magnet test results

Resistance values (ohms)

Temperature	Room temperature	77 K	4.2 K
Main magnet resistance Start-End (switch connected)	52.9	42.1	0.1
Switch heater resistance	27.6	26	25.5
Spare switch heater resistance	28.8	27	26.6
Switch heater(s) to cryostat isolation	∞	∞	∞
Magnet to cryostat isolation (at 500 V)	∞	∞	∞
Main magnet to switch heaters isolation	∞	∞	∞

Current lead voltage drop

The voltage drop is measured at the terminals on the cryostat, while the magnet is held at a constant current

With current for full 4.2 K field in the leads 0.3 volts

Field plots

The magnet was plotted with a Hall probe iat 4.2K in the system cryostat. The Hall probe is calibrated against an NMR probe in an NMR magnet to ensure the accuracy of the measurements and corrected for low temperature operation.

Stray field plots

Note that the stray field from this magnet fills a particularly large volume. Make sure that any personnel near the magnet when operating is aware of the dangers associated with high magnetic fields. This is especially important when the magnet is mounted to produce field in the horizontal direction.

Thermometry

Allen Bradley resistors are used to monitor the magnet temperature during cooldown and operation. Their resistance at room temperature is nominally 270 ohms. The resistance of the leads contributes significantly to this value but has little effect on the readings at the working temperature. The resistors are mounted on the magnet as shown in the system General Assembly drawing and are arranged that one will be on the top and bottom whichever orientation the magnet is fitted to the support.

Calibration of the Allen Bradley resistors

	Room temperature	77 K	4.2 K
A/B1	355	429	4410
A/B2	351	422	4160
A/B3	355	429	4410
A/B4	351	423	4310

Dewar

Specifications (static conditions)

Dewar type Special SMD 29

Liquid helium reservoir evaporation rate ....1500 cm^3/h

Liquid nitrogen evaporation rate ....1500 cm^3/h

Dewar test results

Useful liquid helium volume		88	litres
Liquid helium evaporation rate (static) at	1%	1.26	litres/hour
Liquid helium evaporation rate (static) at	%		litres/hour
Additional consumption with full current in the leads		4.6	litres/hour

Liquid nitrogen volume	138	litres
Liquid nitrogen evaporation rate	0.99	litres/hour

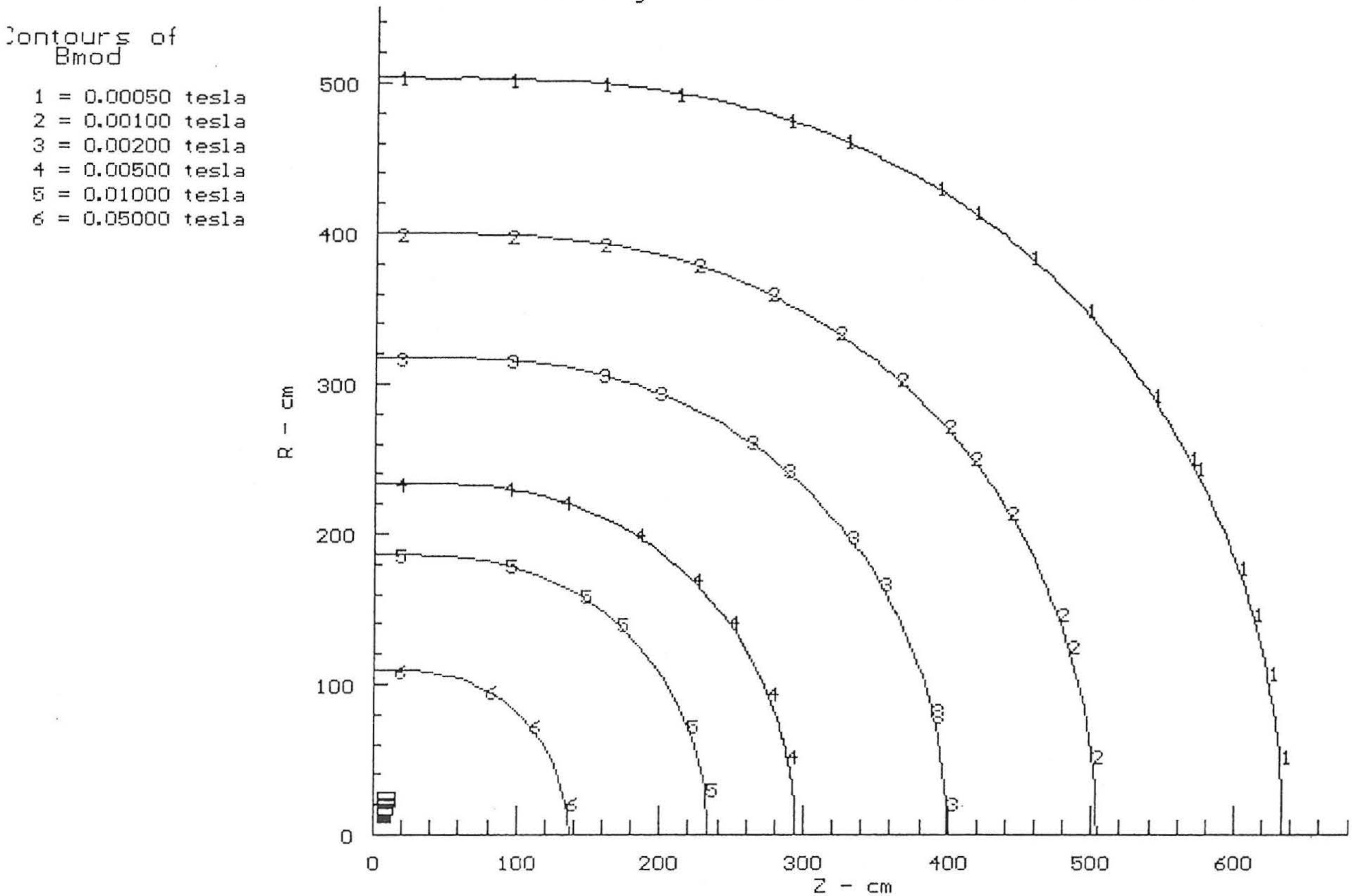
Weight and dimensions of the system

Approximate weight of the system 2000 kg

Minimum ceiling height requirement for sample loading 3700 m

Minimum ceiling height requirement for helium transfer 3100 m

Stray field of 38262 at 12T



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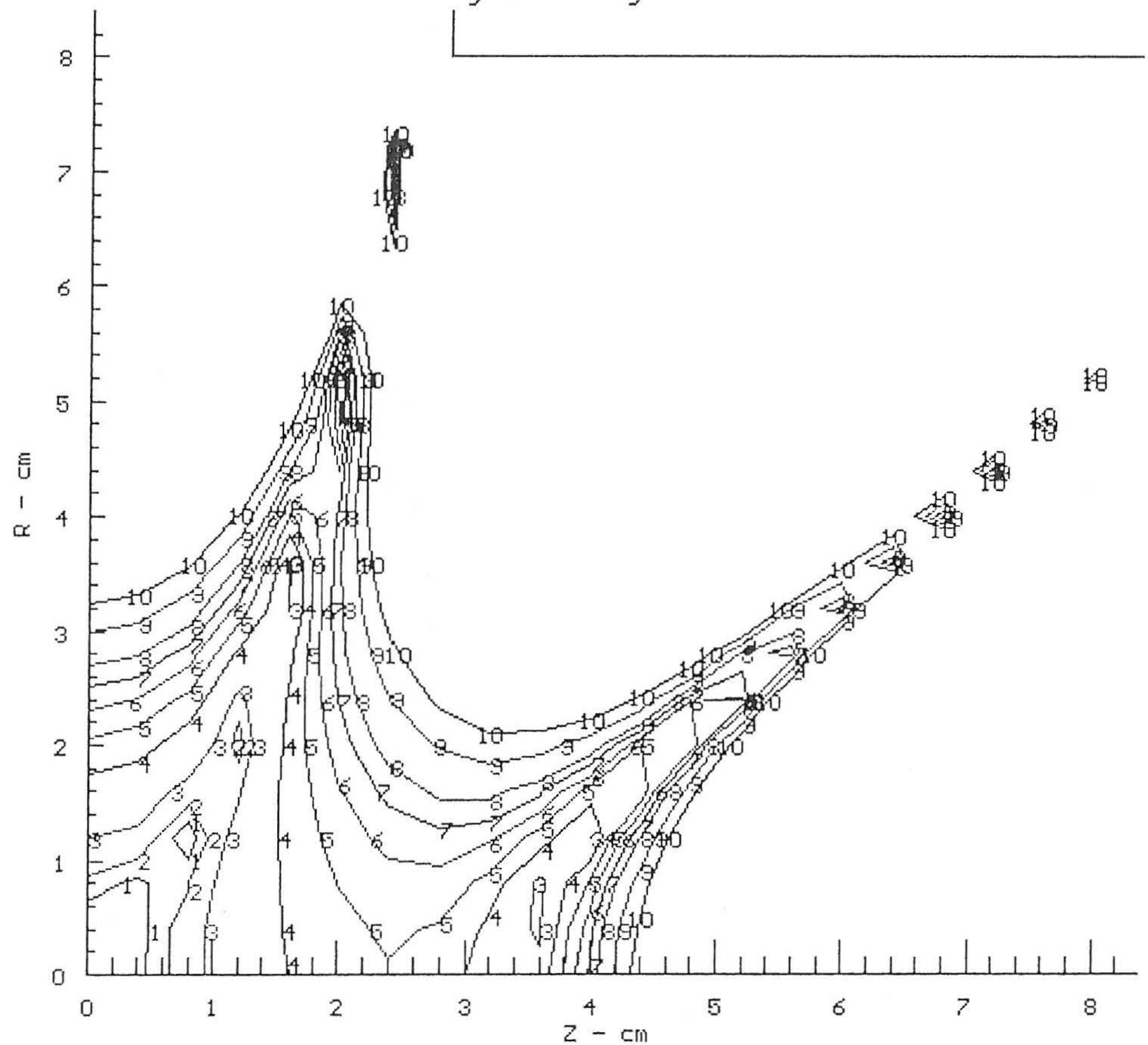
OXFORD/MAGNET VERSION 12.0

homogeneity of 38262

Contours of
. Homogeneity

1 = 0.00500 percent
2 = 0.01000 percent
3 = 0.02000 percent
4 = 0.05000 percent
5 = 0.07500 percent
6 = 0.10000 percent
7 = 0.12500 percent
8 = 0.15000 percent
9 = 0.20000 percent
10 = 0.25000 percent



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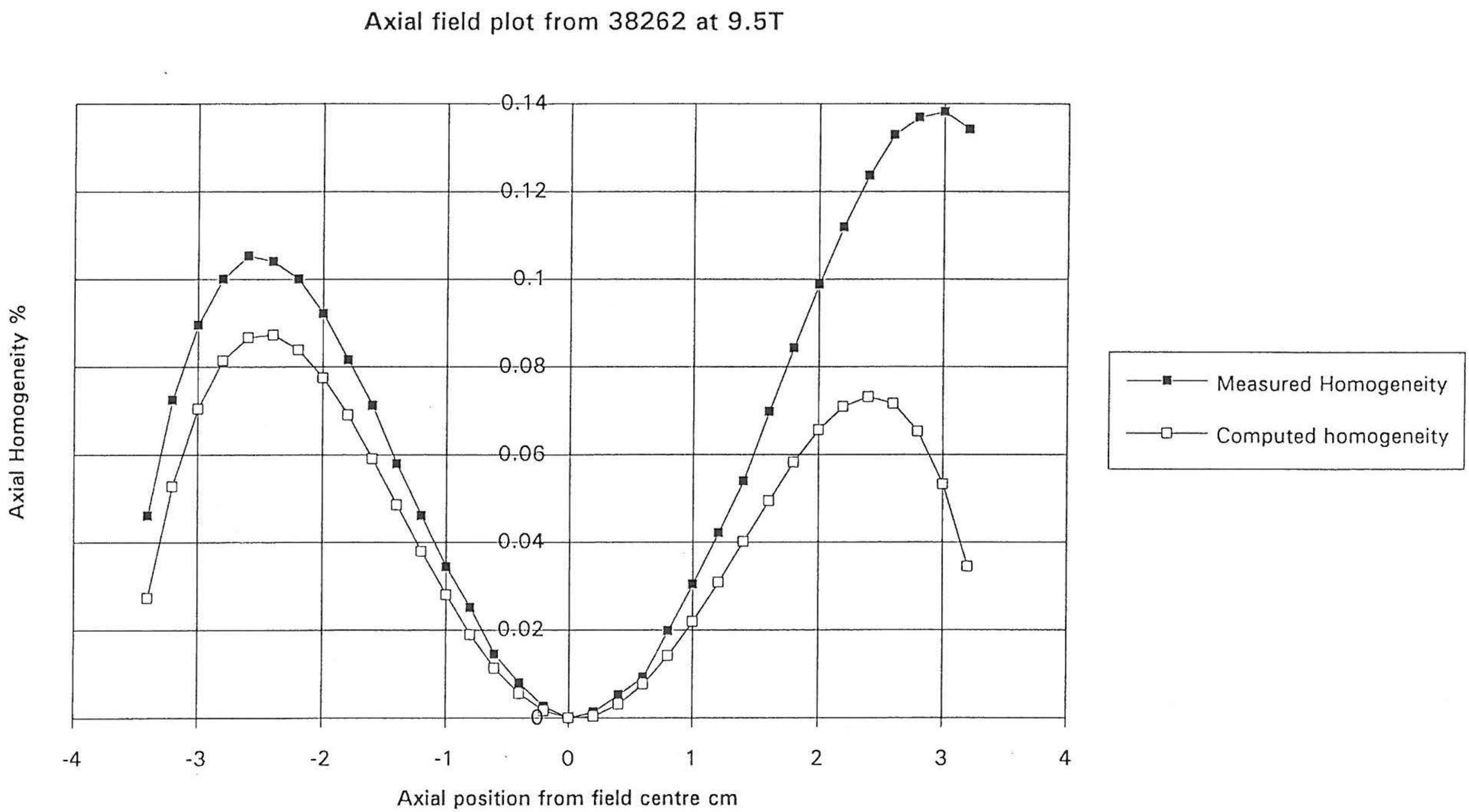
OXFORD/MAGNET VERSION 12.0



Axial field plot from 38262 at 9.5T
Axial Homogeneity %
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-4
-3
-2
-1
0
1
2
3
4
Axial position from field centre cm
Measured Homogeneity
Computed homogeneity

Drawings

Contents

The following drawings are included. Some of these drawings have been folded so that you can see them while you are reading text elsewhere in the manual.

Also included:

Customer support questionnaire. Your feedback will help us to improve our service.

Equipment return form (for use if you have to return any equipment to the factory).

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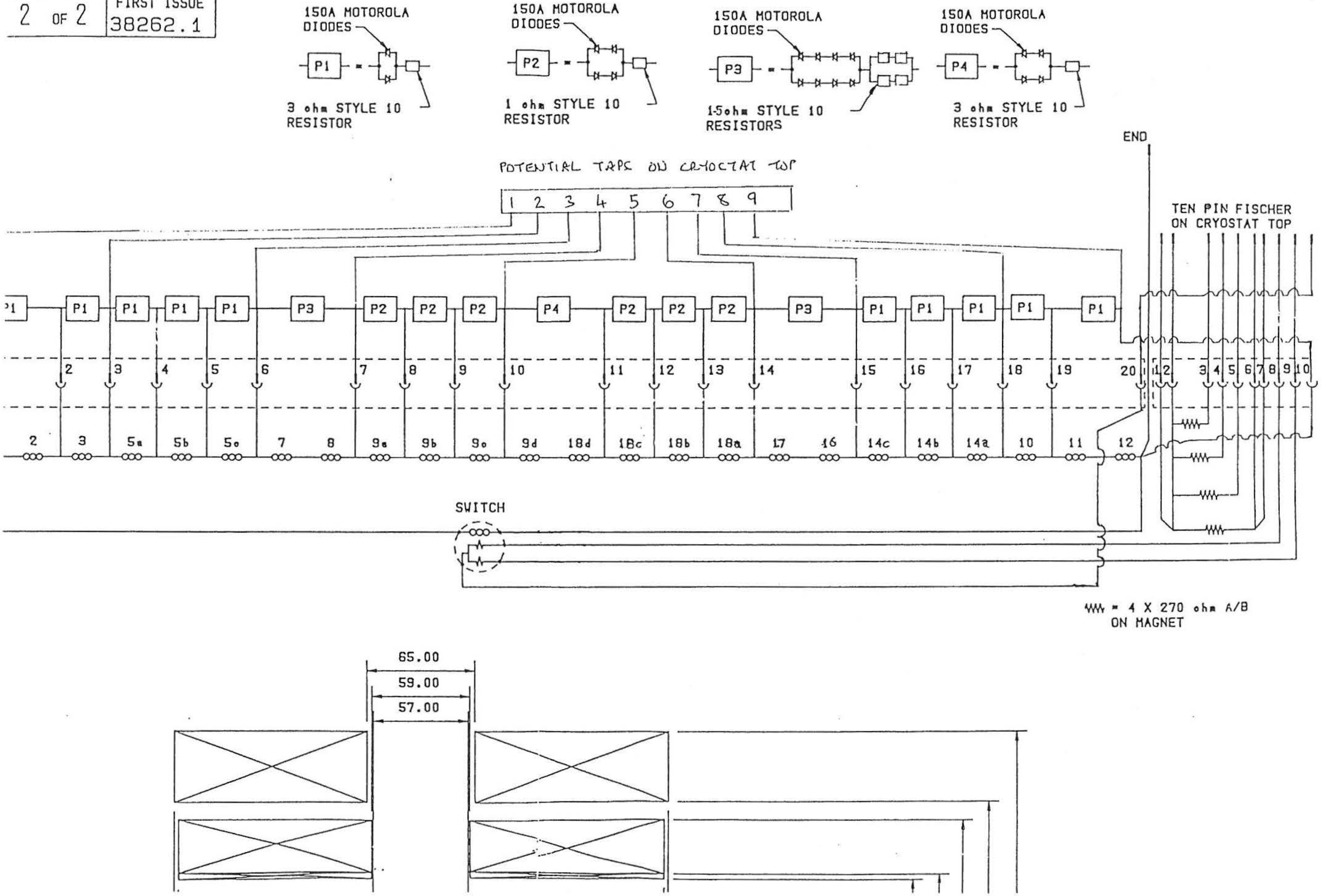

ILM^{200} Family of Cryogen Level Meters

Operator's Handbook

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Issue 1.2

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File reference: ILM.MAN

Warning

Before you operate this equipment for the first time, please make sure that you are aware of the precautions which you must take to ensure your own safety. In particular please read the **Safety** section of this manual.

Explosive Atmospheres

The ILM is intended quite specifically for use with liquid helium and liquid nitrogen. It is not intended for use in an inflammable or explosive atmosphere. It must not be used under any circumstances for monitoring the level of combustible liquids or in the presence of combustible or explosive gases.

Important Note

This manual is part of the product that you have bought. Please keep it for the whole life of the product and make sure that you incorporate any amendments which might be sent to you. If you sell or give away the product to someone else please give them the manual too.

1 Introduction

1.1 Use of this Manual

This manual provides operating and service information for the *Oxford Instruments* ILM^{200} Family of Cryogen Level Meters. Sections 1-4 provide essential information and should be read before operating the instrument for the first time.

The remainder of the manual provides more detail on specific aspects and may be referred to as required. Section 11 attempts to identify some of the more common operating pitfalls and may be useful if problems are encountered.

A Quick Reference guide is provided in Section 13 to help to remind you of the commands and configuration parameters. Please feel free to copy this and keep a copy beside the instrument if you wish.

1.2 Description of the ILM^{200} Family

ILM^{200} is a family of Intelligent Cryogen Level Meters with general application in systems containing liquid helium or liquid nitrogen. The family comprises five instruments. The last two digits of the type number specify the number of helium and nitrogen channels respectively. Thus ILM^{221} is a three channel instrument with two helium channels and one nitrogen channel. From now on, we shall use "ILM" to represent any member of the family.

ILM uses a superconductive wire probe to measure the depth of liquid helium and a capacitance probe to measure the depth of liquid nitrogen. ILM can have up to three measurement channels, with dedicated displays used for each channel.

ILM is microprocessor based and incorporates all the logic needed to control an automatic filling operation or to de-energise a magnet safely should the cryogen level fall below a safe value. All members of the family include an RS232 Serial Computer Interface as standard and if required may be fitted with an optional GPIB (IEEE-488) Interface.

Manual operation of the ILM is by means of front panel push buttons and associated status lamps.

1.3 Principles of Operation

1.3.1 Helium Level Probe

The probe consists of a length of superconductive wire extending from the bottom to the top of the helium reservoir. Normally the probe will be mounted vertically, though other geometries are possible to suit individual shapes of reservoir.

The probe relies on the wire below the liquid surface being more efficiently cooled than that in the gas above the liquid. Thus the Joule heating of the resistive section of the wire is sufficient to keep this above its critical temperature where it is in gas but not where it is in liquid. To maintain this situation requires the correct value of current in the wire. The graph accompanying the probe drawing at the end of this manual shows how this current varies as a function of the temperature of the liquid in the reservoir. With no current in the wire, the entire length will become superconducting. It is therefore necessary to include a small heater resistor in thermal contact with the top of the wire to drive the top end of the wire into its resistive state. Provided the current in the wire is sufficient this resistive region will then propagate down the wire to the liquid surface. When current has been flowing for sufficient time to ensure that the resistive region has reached the liquid, the voltage across the wire is measured and will be directly proportional to the length of wire in gas, from which the liquid level may be calculated. When the measurement has been made, the current through the wire is turned off and the measured reading displayed. The process is repeated at intervals varying from a few seconds to a few hours, depending upon the expected rate of change in the level.

The standard wire used for *Oxford Instruments* probes exhibits a typical resistance of 178 ohms/metre and has an operating current in the range 100 mA to 120 mA. ILM is able to operate with a probe voltage of up to 40 volts, so is typically able to handle probes up to 1.4 metres. (1.0 metres guaranteed with maximum wire current, maximum wire resistivity and minimum mains voltage.)

1.3.2 Nitrogen Level Probe

The nitrogen probe is constructed of two concentric stainless steel tubes. The annular space between these acts as a capacitor with the dielectric consisting of liquid or gaseous nitrogen. Liquid nitrogen has a relative permittivity of 1.45, so that the capacitance increases by around 45% for the portion of the probe that is in liquid. The probe head incorporates an oscillator, which uses the probe capacitance to define its period. Hence the oscillation frequency may be used as an indicator of liquid level. There are no adjustments in the probe head for ILM. The working range of the oscillator (5 kHz to 65 kHz) can handle the full range of probe lengths up to 2 metres.

1.3.3 Why Two Different Sensing Methods Are Used

The capacitance method cannot be used routinely for liquid helium. (It can be used for certain specialised applications where the reservoir is strictly isothermal.) The relative permittivity of liquid helium is only 1.055, which is close to the figure for cold helium gas at 4.2K. Thus the probe would be more responsive to temperature gradients within the gas above the liquid surface, than to the position of the surface.

With modern high-Tc superconductors, it is possible to make a superconductive nitrogen probe. However this would be much less robust than the capacitive probe, which works well for nitrogen. Hence ILM uses the most appropriate sensing technique for each cryogen. By allowing ILM to accept inputs from either type of probe, there is no cost penalty in using two different sensing methods.

2 *Safety*

The following general safety precautions must be observed during the operation, service and repair of this instrument.

2.1 *Protective Ground*

To minimise shock hazard the instrument must be connected to an electrical ground. The ground wire (green/yellow) in the instrument power cable must be connected to the installation electrical ground system. Do not use extension cords without a protective earth conductor. Do not disconnect the protective ground inside or outside the instrument. Do not have external circuits connected to the instrument when its protective ground is disconnected.

2.2 *Working Environment*

The ILM indicator unit is not designed to be water or splash proof. Therefore it should not be exposed to rain or excessive moisture.

Neither the indicator unit nor the probes are designed to be used in areas where there are flammable or explosive gases or fumes.

2.3 *Repair and Adjustment*

Some internal adjustments can be made to ILM. Although we do not encourage you to make these adjustments we try to supply you with enough information to allow you to do it safely. Disconnect the AC power supply before you remove the covers or fuses, because dangerous voltages are accessible on the circuit board and other components. It is not sufficient to switch off the main power switch. Capacitors inside the instrument and the power connector filter, may remain charged after removal of AC power. Discharge these carefully before you start work.

Some fault finding operations can only be carried out with power connected to the instrument. If you have to reconnect the AC power supply with the protective covers removed you must remember that you are putting your life at risk. You should only do this type of work if you are suitably qualified and sufficiently skilled to understand all the risks you are taking.

3 Installation

3.1 Supply Connections

Before applying power to the instrument, ensure that the voltage selector on the rear panel is correctly set for the intended supply voltage.

If necessary, open the voltage selector panel using the slot provided, withdraw the voltage selector and replace it in the correct orientation for the intended voltage. Check that the correct fuses are fitted, then close the voltage selector panel.

Fuse ratings are:

100-120v 1.6A Type T (Slow Blow)
200-240v 0.8A Type T (Slow Blow)

3.2 Probe Connections

Probes are connected by means of 9-way D-sockets on the rear panel. Up to 3 of these may be fitted, depending upon the instrument type. Their position corresponds logically to the associated display on the front panel. Probes 1 and 2 may be used for either Helium or Nitrogen. Probe 3 may only be used for Nitrogen. Pin outs used are the same for either probe and no damage will be caused if the wrong type of probe is plugged in by mistake.

Pin Connections are:

Pin	Name	Helium Probe	Nitrogen Probe
1	V_{HIGH}	V (Top)	n/c
2	V_{LOW}	V (Bottom)	n/c
3	(Unused)		
4	FREQ IN	Link to 5	OUTPUT FREQ
5	FREQ OUT	Link to 4	n/c
6	I_{HIGH}	I (Top)	n/c
7	I_{LOW}	I (Bottom)	0 V
8	+12 V	n/c	+12 V
9	CHASSIS GND	SCREEN	SCREEN

3.3 Compatibility with Earlier Probes

The design of the Helium Probe for the ILM family is unchanged from that for earlier instruments, except for the type of connectors used. Old style probes may be used with the new meter, provided a suitable interconnecting lead is used.

The design of the Nitrogen Probe, though based on the same principle, has changed in detail. Old style probes are not compatible with ILM and should not be connected to it.

Users familiar with *Oxford Instruments* earlier Helium Level meters models HLM2 and 4016 should note that the direction of current flow through the helium level probe is reversed with respect to these instruments. The top of the probe is now positive, where it was previously negative. This has no effect on the operation of the probe. However any users who may have built a dummy "test probe" incorporating an LED to monitor current flow, will need to reverse the connections to the LED. As with earlier instruments, it is important not to swap Voltage (V) and Current (I) leads, since the probe incorporates a small start-up resistor in the top current lead I_{TOP} and will not work reliably if this is transposed with the V_{TOP} lead.

3.4 Auxiliary Port Connections

An auxiliary port is provided in the form of a 15 way D socket on the rear panel. Four digital outputs are available at this port, which may be used to drive relays to control autofilling and external alarms. The outputs are open-collector transistors (Specification as for ULN2803A) and can sink up to 500mA from a supply of up to 12V maximum. When driving an inductive load, it is recommended that a diode is connected across the load to absorb the stored energy. When the optional internal relays are fitted (see below), these are connected to the auxiliary port outputs and provide an effective pull-up resistance to the +11 volt line. The internal alarm sounder is similarly connected to the Relay 4 output.

For low power loads, current may be drawn from pin 15, which is connected via a diode and fuse to the internal unregulated 11 volt line. A maximum of 500mA total may be drawn from this source.

Four further digital output lines are available to drive a small stepper motor. These may be used to control the filling of a small vessel by means of a motorised needle valve.

In addition to the digital outputs there are four digital inputs available. Three of these may be taken high, to inhibit autofilling on the three channels (for example in the event of an empty storage dewar). The forth is unused at present.

Pin connections at the auxiliary socket are:

Pin	Signal Name	Function
1	Output Bit 0	Stepper Motor
9	Output Bit 1	Stepper Motor
2	Output Bit 2	Stepper Motor
10	Output Bit 3	Stepper Motor
3	Output Bit 4	Fill Relay 1
11	Output Bit 5	Fill Relay 2
4	Output Bit 6	Fill Relay 3
12	Output Bit 7	Alarm Relay 4
5	Input K4	Inhibit Autofill 1
13	Input K5	Inhibit Autofill 2
6	Input K6	Inhibit Autofill 3
14	Input K7	(Spare)
7	+5 volt rail	
15	Driver Protection / +11 volt rail	
8	0 volt rail	

3.5 Relay Contact Connections

Internal relays are available on ILM as an option. These have contacts rated to carry up to 5 amps at up to 250 volts AC. They are intended for driving solenoid valves or mains rated contactors directly. To ensure safety when using these relays, connections to these relays are made via terminal blocks within the instrument. ILM should be unplugged from its mains supply before removing the top cover to make connection to the relay contacts. The incoming wires should be brought in via the cable gland on the rear panel. After the connections have been made the cover should be replaced before connecting ILM to the mains supply.

The connections are labelled TB1 to TB4 (corresponding to relays 1 to 4). Three terminals are available for each relay. The terminal nearest the front of the instrument is the Common contact. The middle terminal is the Normally Open contact and the terminal nearest the rear panel is the Normally Closed contact. With the instrument switched off, or the relay not active, Common is linked to Normally Closed. When the relay is active, Common is linked to Normally Open.

3.6 RS232 Serial Data Line Connections

The bi-directional serial data link from the computer is connected via a 25 way D-socket on the rear panel. ILM is configured as a DCE with the standard pin outs given below. The majority of computer RS232 interfaces are configured as a DTE and are fitted with a 25 way D plug. For this type of connector, a simple lead

connecting pin 1 to pin 1, pin 2 to pin 2 etc. is all that is required. For computers fitted with a 9 way D plug for RS232, (AT style COM port), a standard "AT lead" fitted with a 9 way socket and a 25 way plug is required.

Pin connections at the ILM RS232 socket are:

Pin	Signal Name	Notes
1	FG	Linked to Chassis Ground in ILM
2	TD	Data from Computer to ILM
3	RD	Data from ILM to Computer
4	RTS	Linked to Pin 5 in ILM
5	CTS	Linked to Pin 4 in ILM
6	DSR	Linked to +5V when ILM is powered
7	SG	Linked to Digital Ground in ILM
8	DCD	Linked to +5V when ILM is powered

All other pins are open circuit.

ILM does not require signals to be present on any of the "modem control" lines, RTS or DTR (pin 20). RTS is looped back as CTS and logic high levels are returned on DSR and DCD to ensure maximum compatibility with any requirement of the computer.

Voltage levels for the transmitted and received data are:

Tx Data High	> +5.5V
Tx Data Low	< -5.5V
Rx Data High Threshold	< +2.6V
Rx Data Low Threshold	> +1.4V
Max Rx Input Voltage	+/-30V

Data protocols are:

Baud Rate	9600
Tx Start Bits	1
Tx Data Bits	8
Tx Stop Bits	2
Rx Start Bits	1
Rx Data Bits	8
Rx Stop Bits	1 or 2
Parity	None

3.7 The OXFORD ISOBUS

A unique feature of ILM and other *Oxford Instruments* products, is the ability to connect a number of instruments simultaneously, to a single RS232 port on a computer and to control each one independently. This is done by means of an ISOBUS cable which carries a single MASTER connector (25-way D socket) and up to eight, daisy-chained SLAVE connectors (25-way D plugs). Each slave connector incorporates full optical isolation so that the slaves are all isolated from the master and from each other. The slaves connectors draw their power from the individual instruments, via the DCD signal on pin 8. The master connector may draw its power from either DTR or RTS signals from the computer.

To use ISOBUS, a special communication protocol is required, which is part of the command structure of *Oxford Instruments* products and is described in section 6.5.

3.8 GPIB (IEEE-488) Connection (Optional)

If the optional GPIB interface is fitted, connections to the GPIB are made via a standard 24 way GPIB connector. Assignment of the connector pins conforms to the standard IEEE-488.1. Connections should be made using a standard GPIB cable. **GPIB connections should never be made or broken whilst the monitor or any of the instruments connected to the Bus are powered up.** Failure to observe this precaution can result in damage to one or more instruments.

The GPIB interface complies fully with IEEE-488.1-1987 as a talker/listener, able to generate service requests and respond to serial poll and device clear commands. It does not support parallel polling and has no trigger function. Open collector drivers are used on the bus lines so it does not prevent parallel polling of other devices on the bus. Its complete GPIB capability is specified by the Capability Identification Codes:-

SH1 AH1 T6 L4 SR1 RL0 PP0 DC1 DT0 C0 E1

Two lamps are fitted to the rear panel immediately below the GPIB connector, to assist in diagnosing any GPIB communication problems. The RED lamp lights whenever the ILM is addressed to TALK and the GREEN lamp lights whenever it is addressed to LISTEN. The behaviour of the lamps is very dependent on the GPIB monitor in use. Some controllers un-address an instrument at the end of any transaction, in which case the lamps will just blink on for each transaction. Others leave instruments addressed between transactions in which case one or other lamp may remain lit depending on whether ILM was last addressed to talk or to listen.

Before any communication can occur, ILM must be given a unique GPIB address. By default, ILM is supplied with its address set to 24. If this address is already in

use by another instrument on the bus, it can be changed from the front panel via the Test Mode. This is described in section 9.5.

3.9 The GPIB to ISOBUS Gateway

An ILM fitted with a GPIB interface has the ability to act as a GATEWAY to an ISOBUS cable, allowing other instruments to be linked to the GPIB without themselves requiring GPIB interfaces. This can enable other Oxford Instruments' products, for which an internal GPIB interface is not available, to be linked. It offers the additional advantage of optical isolation between these instruments and the GPIB.

To use the gateway, all that is required is GATEWAY MASTER ADAPTOR. This allows the 25 way ISOBUS MASTER socket to be linked to the 25 way RS232 socket on the ILM. The adaptor is a symmetrical 25-way plug to 25-way plug link, with pin connections as shown below.

Beware of using 25-way plug to 25-way plug adaptors, sold as "DCE-linkers" by some suppliers. Several different conventions exist for these, not all of which will work as a Gateway Master Adaptor. The connections required are given in the table below. A Gateway Master Adaptor providing these connections may be obtained from Oxford Instruments.

25 WAY PLUG	25 WAY PLUG
1	1
2	3
3	2
7	7
6	4
4	6

Note that the connections are symmetrical and the adaptor may be plugged in either way round.

The necessary protocols for use as a Gateway Master are included as standard in ILM and are described in section 6.6.9.

4 Operation

4.1 Front Panel Controls

The front panel controls are grouped together in logically related blocks.

POWER

The main ON/OFF switch. A green lamp illuminates whenever the instrument is switched on.

ADJUST

The red RAISE and LOWER buttons provide the main means of adjusting any parameter. In ILM their main use is for adjusting the display reading during the configuration and calibration process. They have no effect on their own but are always used in conjunction with one of the other buttons. Whenever a parameter is being adjusted, its current value is shown on the display. Setting a value involves pressing RAISE and/or LOWER until the required value is shown.

Operation of the RAISE and LOWER controls has been designed to allow large changes to be made relatively quickly whilst at the same time enabling any value to be set exactly. Pressing RAISE or LOWER briefly will cause the value to change by one unit. If the button is held in, the last figure will start to change at about 5 units per second. After 2 seconds, an approximately 10-fold increase in rate will occur, followed after another 2 seconds by a further rate increase and so on. Altogether there are 4 different rates. Whenever RAISE or LOWER is released, the next lower speed will be selected. This allows the user to "home-in" on the required value in a logical way.

A secondary use of RAISE and LOWER is in conjunction with SILENCE, to enter the TEST & CONFIGURATION mode, as described below.

STATUS

Certain functions of ILM, such as Alarm and Magnet Shut-Down in the event of low cryogen levels, are common to all channels. ALARM and SHUT DOWN lamps in the STATUS box allow the operation of these functions to be observed. In particular these conditions remain latched, so that once an alarm or shut down is initiated, it will remain in force, even if the cryogen level is restored. A SILENCE button is provided to clear the alarm and shut down conditions. If the low level causing the condition has been cleared, pressing the SILENCE button will silence the alarm and reset the lamps. If the low level is still present, pressing SILENCE will stop the alarm sounding and release Relay 4. However the ALARM and/or

SHUT DOWN lamps will remain lit, and any of Relays 1 to 3 which are active will remain so. If the alarm has been silenced in this way, it indicates to ILM that the operator is aware of the problem. The ALARM lamp will therefore automatically cancel when the low level condition is removed. The SHUT DOWN condition will not cancel until the SILENCE button is pressed, **after** the low level condition has been cleared. The reason for this is that once a run down has been initiated, it is not advisable to terminate this at some arbitrary magnet current without operator intervention.

The SILENCE control button has a number of secondary SELECT functions which are obtained by pressing this button whilst one or more other buttons are held depressed. If SILENCE is pressed whilst both RAISE and LOWER are held in, ILM enters the TEST mode (see Section 9). If SILENCE is pressed whilst one of the 0% or 100% calibration buttons are held in, calibration and configuration data is STORED in the non-volatile memory and so is retained at power-up.

HELIUM AND NITROGEN DISPLAY

Each channel has its own display section, with a display showing the cryogen level as a percentage 0.0% to 100.0%. If the level sensing probe is unplugged from the instrument, this will be detected and the display will show "**Err**". The display also includes FILL and LOW lamps indicating the status of the channel. In addition this section contains recessed calibration buttons labelled 0% and 100% allowing the instrument to be calibrated to suit a particular probe. Channels used for Helium include an additional RATE button and two lamps indicating whether the unit is sampling at the SLOW or FAST rate. During the actual sample pulse, both lamps light to indicate that current is flowing through the probe.

One, two or three display sections may be present on an instrument depending on the number of channels in use. If an instrument includes one or more channels which have been configured as "unused", their display will remain blank.

4.2 First Time Operation

Switch on the instrument by means of the POWER switch. Check that the green POWER lamp lights.

After about one second the left hand display will show "**S**" followed by a number, which indicates the instrument's "ISOBUS" address (see below). Alternatively if the instrument is fitted with an optional GPIB card the display will show "**G**" followed by a number, indicating its GPIB address assuming this has been selected. After a pause, all displays fitted will show a message indicating the use for which their channel has been configured. This will be "**He**" for Helium, "**N2**" for Nitrogen or

"—" for an unused channel. If a channel has been configured for a continuously energised helium probe, this will be displayed as "**Hec**".

After a further pause the normal channel display will appear, showing the cryogen level. If no probe is plugged into a channel which has been configured to be in use, the display will show "**Err**". On nitrogen channels, the correct level will be displayed immediately. On helium channels, irrespective of the selected sampling rate, the level will be sampled about 10 seconds after switch on. Unless autofilling is in progress the instrument will then default to the slow rate.

4.3 Sample Rate Selection

Helium level is measured by passing a current down a superconductive wire, such that the wire is driven into its resistive state where it is in gas and therefore less well cooled. The measuring process thus introduces a significant heat load into the cryogen. In order to minimise this heat load, the probe is normally only energised for a brief pulse of around 2 to 3 seconds. Between pulses the level is assumed not to vary greatly and the last measured value is displayed. When cryogen is being refilled, the level can change quickly and is sensible to sample at a fast rate with the wire being pulsed every 10 - 30 seconds. At other times the level will only change slowly and it is sufficient to sample it once or twice per hour. At this rate, the heat load due to the pulse is negligible.

Pressing the RATE button switches between FAST and SLOW modes of operation. Whenever the channel is switched to the FAST rate, a sample is taken straight away. Thus if you are already in FAST but wish to take a sample immediately, pressing the RATE button twice will switch to SLOW and back to FAST and so initiate a pulse.

The interval between pulses may be configured for both FAST and SLOW rates over a wide range of values, from within test mode (see section 9.12). It is also possible to configure ILM to switch back to SLOW automatically if left in FAST for more than 15 minutes (see section 9.7).

4.4 Calibration

To obtain accurate level readings of Helium or Nitrogen, ILM must be calibrated for a specific probe. There are two levels of calibration. When the instrument is first configured for a probe, the nominal **active probe length** is supplied, in millimetres. (The active probe length is the working length of the probe. The physical length of the probe will normally be longer than this since the probe will extend from the top of the cryogen reservoir to the top of the cryostat.) From the active probe length, ILM is able to calculate a default calibration based on the

properties of a typical probe. This will usually be within 10% of the correct value, and can suffice for an initial setting before the cryostat is cooled.

For an accurate calibration it is necessary to set two points accurately near the ends of the probe range. This is done by means of the recessed 0% and 100% buttons. These may be pressed with a pointed object, such as a pencil. Whilst holding the button pressed, RAISE and LOWER are used to adjust the display to the required value.

With the cryogen at a known level near zero, the 0% button should be pressed and RAISE and LOWER used so that the known level is displayed. The process is then repeated at a known level near full, using the 100% button. It is often convenient to set the 0% point to exactly 0 when liquid starts to collect during the cryostat cooldown and to set the 100% point to exactly 100% when the reservoir is completely full. The display has been designed to read approximately 1% below 0% and 1% above 100% to simplify this adjustment.

Although the above method may be convenient, it is not necessary to have the levels at exactly 0% and 100% to perform an accurate calibration, provided the actual level is known at the two calibration points. ILM automatically remembers the point at which each setting was made and after any adjustment to one end of the range, it automatically recalculates the complete calibration to ensure that the reading at the other end remains as it was last calibrated. This ensures that there is no interaction between the two calibration points. If this recalibration fails, the display will briefly show "**Err**" after the calibration button is released. In this case the newly calibrated point will remain correct but the other end of the range may have been moved. The usual reason for this is that the active length of the probe in use is not sufficiently close to the active length entered during configuration. Setting a more accurate value will resolve the problem. The same problem may also make it impossible to set the required display number by means of RAISE and LOWER. Again check and correct the active length in the configuration.

Note that it is not accurate to set the 0% point for either Helium or Nitrogen probes when the cryostat is still warm, since the properties of warm gas are not the same as those of the cold gas which will normally be present in the reservoir above the liquid surface.

If an approximate reading is required without calibrating a probe, the default settings for 0% and 100% for the probe's nominal active length may be restored by pressing both 0% and 100% together. ILM will restore the defaults and indicate this by briefly displaying "**dEF**".

4.5 Storing Calibration and other Power-Up Defaults

Whenever any data has been changed, which is intended to be retained after power down, this must be deliberately STORED. This write operation is achieved by holding any of the 0% or 100% calibration buttons pressed in, whilst pressing and releasing SILENCE. The display will briefly show **"Stor"** indicating that the data has been correctly stored. It does not matter which calibration button is pressed, the entire calibration of the instrument for all channels will always be saved in a single operation.

If instead of showing **"Stor"**, the display shows **"Prot"**, this indicates that the memory is protected by the hardware WRITE-ENABLE switch being in the OFF position. This is Switch 1 of a small 2 way Dual-in-Line switch SW2 on the motherboard. Set it to the "ON" position and try again. (Switch 2 of this switch is used to disable the internal alarm.)

The switch need only be returned to the OFF position if it is desired to prevent any possibility of the data being changed by someone tampering with the front panel.

5 Auto-Fill and Alarms

5.1 Level Thresholds

There are three threshold levels associated with each channel. These are used to control an automatic filling operation, or to sound an audible alarm or de-energise a magnet in the event of low cryogen level. The three levels are called **FULL**, **FILL**, and **LOW**, with FULL normally being the highest level and LOW the lowest. All three levels may be adjusted anywhere within the 0% to 100% range by means of the test mode. (See section 9.13.) The standard factory default settings are 90% for FULL, 20% for FILL and 10% for LOW.

5.2 Automatic Filling

FILL and FULL levels are intended for use with automatic re-filling. Autofill can be enabled or disabled by means of the configuration parameter for the channel, set in test mode. When Autofill is enabled, filling will start when the level falls below the FILL threshold. Thereafter filling will continue until the level rises above the FULL threshold. When filling is in progress the FILL lamp will be lit.

There are two alternative methods by which an autofill may be controlled. Selecting which of these is to be used forms part of the Configuration Parameter set from within Test Mode (see section 9.7).

The normal method of controlling an autofill is by means of the digital logic level at the Auxiliary socket and/or the associated relay for the channel concerned. The logic line is pulled low and the relay (if fitted) is energised whilst filling is in progress.

An alternative method of controlling filling is to use a motorised needle valve. This may for example be used for filling a small reservoir from a main helium bath. ILM supports the use of a small stepper motor to drive such a needle valve. The motor is connected to the auxiliary port. When the level falls below the FILL threshold to motor will slowly open the needle valve. When it rises above the FULL threshold the motor will slowly close the needle valve. Whilst the level is between the two thresholds the needle valve setting will not change. By bringing the two thresholds close together a relatively constant level may be maintained within the small reservoir.

There is no motion of the needle valve when ILM is first switched on, provided the level is between the FILL and FULL levels (unlike the ITC500 family auto-gas-flow needle valve). From this initial position the ILM will provide up to 32767 step pulses in either direction. The motor and gear box used should be selected such that this number of pulses is more than sufficient to drive the valve from one end of its travel to the other and the needle valve should be fitted with a slipping

clutch or a low-torque motor used, so that attempting to drive the needle beyond its normal travel will cause no damage.

5.3 Automatic Rate Switching

When autofilling is used for a Helium vessel, it is advisable to switch to the FAST sampling rate for the filling operation. Otherwise the vessel is likely to be full before the next sample occurs! A separate, optional part of the configuration parameter (see section 9.7) allows automatic control of the sampling rate. The strategy is that whenever the level is below the FILL threshold, the sampling rate switches to FAST. It will then remain in FAST until the level is above the FILL threshold and the level has not risen for at least 15 minutes. This indicates that either the fill is complete or the process has stopped for some reason. In either case there is no need to remain in the FAST rate, so ILM switches back to LOW.

Note that even on systems which do not have an autofill, it can be useful to have automatic rate switching active, since it prevents cryogen wastage if the operator should leave the rate set to FAST by mistake. If automatic rate switching is being used in this application, the FILL threshold should be set to -1%, so that ILM will never see a level below the FILL threshold and so will never automatically switch to the FAST rate.

5.4 Audible Alarm

When the cryogen level falls below the LOW level, ILM is able to sound a built-in audible alarm, to alert the operator to the low level. At the same time an external signal is available (relay 4) which may be used to drive a remote alarm. When the alarm sounds, pressing the SILENCE button will stop the noise, but leave the ALARM lamp lit until the cryogen is replenished above the LOW level.

If a remote alarm is in use and the internal alarm sounder is not required, it may be switched off by means of switch S2/2 on the main circuit board (see section 4.5).

5.5 Automatic Shut Down

An alternative to sounding an alarm on low cryogen level, is to automatically shut down the system. In many cases where the cryogen reservoir contains a superconducting magnet, shutting the system down involves safely de-energising the magnet. This may be achieved by linking the relay 4 output to the magnet power supply to initiate de-energising the magnet. When an automatic shut down is happening, the SHUT DOWN lamp will light. This cannot be cleared by the SILENCE button until the low cryogen level has been rectified.

6 Remote Operation

6.1 Introduction

ILM may be remotely operated by means of its RS232 or GPIB interface. This allows a computer to interrogate the instrument. For compatibility with other *Oxford Instruments* products, a mode is available allowing the computer to control the instrument and initiate sampling pulses. However it is not envisaged that this would be used for routine operation.

6.2 Communication Protocols

ILM is always fitted with a Serial (RS232) interface. In addition, an optional GPIB (IEEE-488) interface may be fitted. Details of the hardware communication protocols for the two interfaces are given in sections 3.6 and 3.8 respectively.

The same command protocols are used for the Serial and GPIB interfaces.

All commands consist of a string of printing ASCII characters, terminated by a Carriage Return character. A Line Feed character may optionally be sent after the Carriage Return but is ignored by ILM.

Unless the command starts with a "$" (dollar) character, all commands will evoke a response from ILM. The response will consist of a string of one or more printing ASCII characters and will be terminated by a Carriage Return Character. This may optionally be followed by a Line Feed character.

The response will normally be sent immediately following the command. If a front panel button is pressed when the command is received, the response may be delayed until the button is released. With the Serial Interface in use, the response will be transmitted automatically as soon as it is available. With the GPIB interface, the response will be sent when the instrument is next addressed to talk.

If the first character of a command is a "$", the command will be obeyed but no response will be sent (see section 6.5).

ILM will accept a command string at all times. If a computer linked by the serial (RS232) port is unable to accept data from ILM at the full rate of the 9600 baud interface, the "W" command may be used to instruct ILM to send more slowly.

6.3 Commands and Responses

Commands to ILM all consist of a single letter, optionally followed by a numeric parameter, the whole being terminated by a Carriage Return. All commands are based on Upper Case letters with mnemonic significance. The response sent by ILM varies depending on the command. Usually it consists of the Command letter

received, followed by the value of any data requested. Where a command instructs ILM to carry out an action rather than to send data, the command letter alone will be returned.

If a command is not recognised, has an illegal parameter or cannot be obeyed for any reason, an error response will be sent. This consists of a "?" (question mark), followed by all or part of the command string in question. To simplify error handling in the computer, the "?" will always be the first character returned.

6.4 Numeric Parameters

All numeric parameters are treated as signed integers and are sent as a string of decimal digits. The range of acceptable numbers is -32768 to +32767. Alternatively, positive numbers in the range 0 to 65535 will be accepted, if preceded by a "#" (hash) symbol. Numbers outside this range will give an error.

For positive numbers, the "+" sign is optional, as are leading zeros. Any spaces, full stops and commas embedded within the number are ignored.

6.5 Use with OXFORD ISOBUS

The OXFORD ISOBUS allows a number of instruments to be driven in parallel from a single RS232 port on a computer, using a special cable assembly.

To allow separate instruments to be distinguished, each is allocated a unique address in the range 0 to 8, held in non-volatile memory.

When operating on ISOBUS, an instrument must be able to recognise and respond to commands addressed to it, whilst ignoring commands addressed to other instruments. This is achieved by starting all commands with a special ISOBUS control character.

When more than one powered-up instrument is connected on ISOBUS, no command should be issued which does not have an ISOBUS control character as its first character. Issuing such a command would result in an unintelligible response, as all instruments would reply together. (N.B. This will only result in lost data. No hardware damage will be caused.)

Following the control character and its parameter (where required), the rest of the command follows the form described above. The response of the instrument depends on the initial control character in the following manner:

@n (At) addresses the command to instrument number n, where n is a digit in the range 0 to 8. This instrument obeys the command and returns its usual response. All other instruments ignore the command and send no reply.

$ (Dollar) instructs all instruments to send no reply. This is normally used to precede a command being sent to all instruments simultaneously, and prevents a conflict as they all echo the command together.

It may also be used in non-ISOBUS applications if the computer does not wish to receive a response.

It should be used with caution however, since all responses are suppressed, including the "?" error response. Thus the computer has no way of knowing if a command has been received or even if the instrument is connected.

If a command is to be addressed to a specific instrument, but no reply is required, it is permissible to use "$" and "@n" together. The "$" should always come first.

& (Ampersand) instructs an instrument to ignore any following ISOBUS control characters. It is included in the ISOBUS protocol to allow instruments whose command repertoire includes "@", "$", "&" or "!" to be used on ISOBUS. ILM does not require the use of this command.

!n (Exclamation) instructs the instrument that from now on, its address is to be n. This command is included here since it is relevant to ISOBUS operation. However for obvious reasons, it should not be sent when more than one instrument is powered up and connected to ISOBUS. (It would result in all instruments having the same address!) The command is intended for initial setting up of instruments, one at a time. To avoid inadvertently changing addresses, the "!" command will only be obeyed following a "U" command with a non-zero password (see section 9). Note that the address set this way is the ISOBUS address, not the GPIB address. The latter cannot be set via the interface, since until an address is defined, GPIB communication is not possible.

6.6 The GPIB Interface

The GPIB Interface is an accessory allowing the ILM to be computer-controlled by means of the General Purpose Interface Bus (GPIB), also known as HPIB and IEEE-488 interface.

When installed, it supplements rather than replaces the RS232 Serial Interface. It allows an instrument to be controlled either by GPIB or RS232 (not both simultaneously). In addition when operating under GPIB control, the RS232 interface may be used as a GATEWAY to further OI instruments, not themselves fitted with a GPIB interface.

The instructions which follow assume some basic familiarity with the concepts of the GPIB. This will typically be provided as part of the documentation supporting a GPIB controller card for a computer etc.

Even with the GPIB interface fitted it is still possible to communicate with the instrument via the RS232 interface in the standard way. This is the default condition after power up (or t=0 re-start) and ISOBUS addressing may be used if desired.

Provided the GPIB interface has not been deliberately DISABLED by setting its address to 0 (see section 9.5), it may be switched to the GPIB IN-USE state at any time. This occurs automatically when a GPIB Controller asserts the REN line and addresses the interface either to talk or listen at the GPIB address selected. Once it has been put into the GPIB IN-USE state, it remains in that state until power down or until a t=0 re-start.

6.6.1 Sending Commands via the GPIB

Commands sent via the GPIB follow exactly the same syntax as for the RS232 interface. Commands must be terminated by a Carriage Return <CR> character, (ASCII 13). A Line Feed <LF> may be sent if desired but is not needed and will have no effect. (Your GPIB controller may send <CRLF> by default). Provided it is operating (as opposed to being in TEST mode) the ILM will accept commands at all times. Where commands produce a response message, this should be read before a further command is issued.

6.6.2 Accepting Responses via the GPIB

Messages returned via the GPIB consist, by default, of an ASCII character string, terminated by a <CR>. If your controller expects <LF> as a terminating character, this may be achieved by sending an initial "Q2" command after power up. Note that the "Q2" command itself produces no response message but that all subsequent messages are terminated by the <CRLF> pair. The interface never asserts the EOI line at the end of a message, instead allowing either <CR> or <LF> to be used as the End-of-String (EOS) character.

6.6.3 The Status Byte, Use of a Serial Poll

One of the problems with a GPIB interface is knowing when a message is available to be read. If a device is addressed to TALK but has no data available, it will wait indefinitely, unless the controller includes a TIMEOUT facility (see section 6.6.10).

There are a number of ways by which the controller can determine when data is available. The simplest, but least reliable way is to "know" from the command which has been sent, whether a reply is to be expected. This is fine until something unexpected happens.

A better alternative is to read a STATUS BYTE from the instrument by conducting a SERIAL POLL of it. The ILM interface will always respond to a serial poll and will return a status byte. Three bits in this byte have significance for ILM as follows.

Bit 6 (Value 64 decimal)	RQS (Requesting Service)
Bit 4 (Value 16 decimal)	MAV (Message Available)
Bit 1 (Value 2 decimal)	BAV (Byte Available)

The bit positions for the RQS and MAV bits are as specified in IEEE-488.1 and IEEE-488.2 respectively. (Note the convention here is that the Least Significant Bit is Bit 0. This is sometimes referred to as data line D1. Thus lines D1 to D8 correspond to Bits 0 to 7.)

The BAV bit is set as soon as at least one byte is available to be read. The MAV bit is set when a complete message up to and including the <CR> or <LF> character is available to be read. The RQS bit indicates that the instrument has requested service by asserting the GPIB SRQ line true (see section 6.6.4).

The status byte may be read as many times as the controller wishes. The MAV and BAV bits will reflect the current status of the interface at the time the byte is read (but see below). Hence once set, they will remain set until the message has been read. The RQS bit behaves differently (in accordance with IEEE-488.1). The first time the status byte is read after the interface has requested service, it will be set. The act of reading the status byte clears the service request bit and at the same time allows the interface to release the Service Request Line (see below). It will not be asserted again unless a further service request is issued.

ILM updates the status byte every millisecond. Thus if the status byte is read within 1mS of reading data from the interface, the MAV and BAV bits may not yet have been cleared, even though all available data has been read. If these bits are found to be unexpectedly set immediately after a data read, a second read of the status byte at least 1mS later will confirm whether there really is data remaining.

6.6.4 Use of the Service Request Line

The interface will issue a service request (by pulling the SRQ line), at the point a complete message becomes available to be read, (i.e. at the point at which MAV is first set), unless the interface is already addressed to TALK at that point. In the latter case no service request is required since the controller is already waiting to read the data or is in the process of doing so.

Hence use of the SRQ line allows a suitably equipped controller to handle all data from the interface on an interrupt basis. If the controller is not equipped to do this, it may simply ignore the SRQ line and poll the status byte on a regular basis until the MAV bit indicates data is available.

6.6.5 *Use of the Device Clear Function*

When the GPIB interface receives a Device Clear message from the controller, it responds by clearing all the communication buffers to their empty, power-up state. It does not reset any of the temperature control functions to the power-up state. Device Clear may thus be safely used to empty the buffers if these have been filled with a number of unread messages. Device Clear may be sent by either the GPIB DCL message (which clears all connected devices), or by means of the SDC message addressed specifically to its address.

Note that if an ISOBUS GATEWAY is in use, only the buffers in the MASTER instrument are cleared. If data is currently being transmitted from a SLAVE instrument to the MASTER, this will be read into the buffer after it has been cleared.

6.6.6 *Use of the Interface Clear (IFC) Function*

Receipt of the single line IFC message clears the GPIB interface functions as specified by IEEE-488.1. It does not clear any pending data in the buffers. Nor does it have any effect on operation of the temperature control function.

6.6.7 *Non-Implemented Features of the GPIB*

The GPIB Remote Enable (REN) line is used only to alert the interface to the presence of an active controller. It is not used for LOCAL/REMOTE switching which is carried out by the simpler "C" command, for compatibility with RS232 operation. Similarly the GPIB LOCAL LOCKOUT command and GOTO LOCAL commands have no effect. This functionality too is a part of the "C" command.

The interface does not respond to a Parallel Poll request. However since it uses open collector data buffers, it can co-exist on the GPIB with other instruments which do have a Parallel Poll facility.

6.6.8 *Compatibility with IEEE-488.2*

Compatibility with certain aspects of this extension to the original standard has already been mentioned in a number of places (for example the format of the Status Byte). However details of the command sequences and formats within messages, error handling and status reporting all follow the existing ILM syntax and protocols used on RS232. This precludes complete compliance with the rather more complex IEEE-488.2 syntax. In particular there is no attempt to support the "Standard Commands for Programmable Instruments" (SCPI).

6.6.9 Use of the GPIB Interface as a GATEWAY to ISOBUS

When the interface is operating in the GPIB IN-USE state, all characters received via the GPIB are echoed back out on the RS232 line. Similarly any characters received on the RS232 are made available to be read by the GPIB controller (with MAV, BAV and RQS being set appropriately as above). This allows one or more other instruments to be connected to the first instrument using the OXFORD ISOBUS. These may share the benefits of being controlled by the GPIB controller, whilst at the same time enjoying the advantages of optical isolation provided by ISOBUS. To use this GATEWAY, requires only a GATEWAY MASTER ADAPTOR, as described in section 3.9.

No special command protocols are required to access the GATEWAY. All *Oxford Instruments* products fitted with RS232 can be accessed in this way. The command strings sent to individual instruments when used in this way are simply prefaced by their ISOBUS ADDRESSES as described above. Note the distinction between the GPIB address which is common to all the instruments on the GATEWAY and their individual ISOBUS addresses which form a part of the message string, preceded by the "@" character. The ISOBUS GATEWAY MASTER (i.e. the instrument actually fitted with the GPIB interface) always has the ISOBUS address "@0". This must be used when addressing this instrument, since a command sent with no "@" prefix would be seen by all instruments (just as for a simple ISOBUS system).

6.6.10 Writing a "Rugged" GPIB Control Program

A lot of effort has been put into making the design of the GPIB interface as tolerant as possible. However in any computer interface designed to operate unattended for periods of time, it is essential to assume that data corruption may occur at any time. Usually this is due to static, power line surges, operator error etc. Any controller program should be designed to cope with this. In particular all attempts to write data to or read data from any instrument should have a TIMEOUT facility built in. The GPIB handshake sequence makes it all too easy for lost data to result in the bus hanging indefinitely. When a timeout occurs the controller should attempt to assess what is happening. In the case of the ILM GPIB interface this is best done by means of a serial poll. If this too times out, the next recourse should be to reset the interface by means of the Interface Clear (IFC) line. If a serial poll is still unable to get a response, the controller must assume that the instrument has been switched off, failed or a connector has fallen out. As a last resort it should attempt to alert an operator and/or if possible continue operating the remaining instruments.

7 *Command List*

A brief summary of the available commands is given below. Fuller details are given in the following section.

Commands fall into 3 categories:

MONITOR COMMANDS	which are always recognised.
CONTROL COMMANDS	which are only recognised when in REMOTE control.
SYSTEM COMMANDS	which are only recognised after receipt of the correct "UNLOCK KEY".

In the list which follows, "n" represents a decimal digit 0-9.

MONITOR COMMANDS (always recognised)

Cn	SET CONTROL LOCAL/REMOTE/LOCK
Qn	DEFINE COMMUNICATION PROTOCOL
Rnn	READ PARAMETER nn
Unnnnn	UNLOCK FOR "!" AND SYSTEM COMMANDS
V	READ VERSION
Wnnnn	SET WAIT INTERVAL BETWEEN OUTPUT CHARACTERS
X	EXAMINE STATUS

CONTROL COMMANDS (recognised only in REMOTE)

Fnn	SET TO DISPLAY PARAMETER nn
Gnnn	SET STEPPER MOTOR POSITION
Sn	SET CHANNEL n to SLOW
Tn	SET CHANNEL n to FAST

SYSTEM COMMANDS (recognised only after correct Unnnnn command)

Y	LOAD ENTIRE RAM CONTENTS
Z	DUMP ENTIRE RAM CONTENTS
!	SET ISOBUS ADDRESS (See section 6.5)

8 Command Syntax

8.1 User Commands

Cn COMMAND

The control command sets ILM into LOCAL or REMOTE. It is provided primarily for compatibility with other *Oxford Instruments* products, so that all may be switched into REMOTE simultaneously with a $Cn command. At power up ILM defaults to the C0 state. Allowed values are:

C0	LOCAL (Default State)
C1	REMOTE & LOCKED (Front Panel Disabled)
C2	LOCAL (Same as C0 for ILM)
C3	REMOTE & UNLOCKED (Front Panel Active)

In the C3 state, buttons such as RATE and SILENCE can be used in the normal way. While any buttons are held pressed in the C3 state, the instrument will not respond to any remote commands. Instead these are held pending and acted upon when the button is released. Computer programs should either be written to tolerate this delay or should put the instrument into the C1 state to completely disable the front panel controls.

Qn COMMAND

Defines the communication protocol.

Currently only 2 values of n are significant:

Q0	"Normal" (Default Value)
Q2	Sends <LF> after each <CR>

Note that unlike all other commands, the Q command does not produce an echoed response to the computer. (Having changed the communication protocol, it automatically clears the communications buffer.)

Rnn COMMAND

The READ command allows the computer to interrogate any of a number of variables. The returned value is always an integer as defined in section 6.4. Allowed values for nn are listed below. (R11 and above are intended as service diagnostics and are unlikely to be of use to the user.) Other values in the range

R0 to R13 will return a value rather than an error response, but the value will not be of significance.

R1	CHANNEL 1 LEVEL
R2	CHANNEL 2 LEVEL
R3	CHANNEL 3 LEVEL
R6	CHANNEL 1 WIRE CURRENT
R7	CHANNEL 2 WIRE CURRENT
R10	NEEDLE VALVE POSITION
R11	CHANNEL 1 INPUT FREQUENCY / 40
R12	CHANNEL 2 INPUT FREQUENCY / 40
R13	CHANNEL 3 INPUT FREQUENCY / 40

Unnnnn COMMAND

The UNLOCK command allows access to the SYSTEM commands. This set of commands are intended for diagnostic and configuration purposes and have the power to erase or modify the contents of the memory. The U command must be sent with the correct KEY parameter before these commands may be used. The KEY value for these commands is 9999.

A lower level of key protection is provided for the "!" command, to avoid accidental errors. Any non-zero value will unlock this command.

Two additional special key values are significant. These are intended specifically to allow a GATEWAY MASTER instrument to be used to load RAM data (via a "Y" command) to a SLAVE instrument, without the data being "obeyed" as commands, by the MASTER. A value of U1234 puts the MASTER to SLEEP, until the specific sequence U4321 is detected. Whilst it is asleep, all data received via the GPIB interface is passed on to the slave but ignored by the master.

Thus the allowed values of U are:

U0	LOCKED (Power-up Default)
U1	"!" COMMAND UNLOCKED
U1234	SLEEP
U4321	WAKE UP
U9999	"Y" COMMAND UNLOCKED

V COMMAND

The VERSION command requires no parameters. It returns a message indicating the instrument type and firmware version number.

Wnnnn COMMAND

The WAIT command sets a delay interval before each character is sent from ILM via the computer interface. This allows ILM to communicate with a slow computer with no input buffering. The parameter nnnn specifies the delay in milliseconds. It defaults to zero at power-up.

(N.B. the W command does not reduce the rate at which ILM can accept data from computer.)

X COMMAND

The EXAMINE command allows the computer to read the current ILM STATUS. It requires no parameters and will return a message string of the form:

XabcSuuvvwwRzz

where "a" "b" and "c" are three decimal digits defining the use of the three channels and "uu", "vv" and "ww" are three pairs of hexadecimal (base 16) digits indicating the current status of the three channels. A further pair of hexadecimal digits "zz" indicate the current status of the logic level outputs (and relays if fitted). The significance of the various sections of the status message is described in more detail, with examples, in section 8.2 below.

Fnn COMMAND

The FRONT PANEL DISPLAY command sets which channel will be displayed on the channel 1 display for diagnostic purposes. The parameters which may be displayed are as listed for the "R" command above.

Gnnn COMMAND

Allows the needle-valve stepper motor (if fitted) to be set to a new position. In ILM the absolute position of the needle valve is not defined, so this command is unlikely to be of use in normal operation. It is provided to assist in testing the operation of a needle valve.

Sn COMMAND

Sets channel n to SLOW sample rate. (Note that this may be over-ridden by autofill if the cryogen level is below the FILL threshold and the channel has been configured for automatic rate switching as described above.

Tn COMMAND

Sets channel n to FAST sample rate and initiates an immediate sample pulse.
If automatic rate switching is active, the rate will revert to SLOW after 15 minutes, if the level is not rising.

Yn COMMAND

The Y command allows the contents of the RAM memory to be loaded in binary, via the serial interface. It is not intended as a user command. If n is omitted or has the value 2, only the first 2 kilobytes of the memory are loaded. If n has the value 8, the entire 8 kilobytes are loaded. (In general all calibration parameters of interest are held within the first 2 kB.) Note that after loading the memory in this way, the new content will be lost at power-down, unless it has been saved by a STORE sequence as described in section 4.5.

Zn COMMAND

The Z command allows the contents of the RAM memory to be dumped in binary, via the serial interface. It is not intended as a user command. Like the Y command, omitting n or setting it to 2 results in a 2kB dump. Setting n to 8 gives a full 8kB dump.

8.2 Interpreting the Status Message

The status message comprises three separate pieces of information indicating Channel Usage, Channel Status and Relay Status as described above.

Channel Usage is given by a single digit for each channel. Note that this only takes values in the range 0 to 9 so may be treated as a decimal digit. (However it can equally well be treated as a hexadecimal digit for consistency with the remaining part of the status message if you so wish.)

Channel Status is given by a pair of Hexadecimal Digits for each of the three channels. The pair together are best thought of as representing an 8 bit binary number, where the bits taken singly or in pairs each have a separate significance

Relay Status consist of a single pair of Hexadecimal digits. This again is best thought of as an 8 bit binary number where the bits each have a separate significance.

The significance of the individual bits within the message is given in the tables and examples which follow. There is some duplication of information between the various parts of the status message. This is done deliberately so that in any application only the most appropriate part of the message need be monitored. Thus the refilling process may be monitored either from the point of view of what is happening to each channel, from within the Channel Status; or from which relays and valves are being operated, from the Relay Status. It is unlikely that any one application will require all the information in the status message.

The tables which follow give the significance of the three portions of the message.

Xabc CHANNEL USAGE (The three digits correspond to the three channels)

Allowed values are:

0	Channel not in use
1	Channel used for Nitrogen Level
2	Channel used for Helium Level (Normal Pulsed Operation)
3	Channel used for Helium Level (Continuous Measurement)
9	Error on channel. (Usually means probe unplugged)

Suuvvww   CHANNEL STATUS (Two digits per channel)

The pairs of digits are most logically thought of as representing an 8-bit binary number, where the bits have the following significance.

Bit 0	Current flowing in Helium Probe Wire	
Bit 1	Helium Probe in FAST rate	
Bit 2	Helium Probe in SLOW rate	
Bits 3,4	Auto-Fill Status	
00	End Fill	(Level > FULL)
01	Not Filling	(Level < FULL, Level > FILL)
10	Filling	(Level < FULL, Level > FILL)
11	Start Filling	(Level < FILL)
Bit 5	Low State Active	(Level < LOW)
Bit 6	Alarm Requested	(As defined by CONFIG BYTE)
Bit 7	Pre-Pulse Current Flowing	

Rzz   RELAY STATUS

The single pair of digits represent an 8-bit binary number, where the bits have the following significance:

Bit 0	In Shut Down State
Bit 1	Alarm Sounding (Relay 4 Active)
Bit 2	In Alarm State (Sound may have been SILENCED)
Bit 3	Alarm SILENCE prohibited *
Bit 4	Relay 1 Active
Bit 5	Relay 2 Active
Bit 6	Relay 3 Active
Bit 7	Relay 4 Active (Duplicates Bit 1)

* Note that in certain configurations, the ALARM relay may be used to initiate an automatic run down of a magnet. In this case the SILENCE button is prevented from disabling the alarm, since the run down process must not be cancelled unintentionally.

8.2.1 Example Sequence

The sequence which follows shows the status messages returned from a typical instrument during normal operation.

The instrument is an ILM211. We will assume that the nitrogen level remains constant at 100% throughout the sequence and will follow the effects of variation in helium level through an autofill sequence. The instrument is configured via test t.05 as follows:

Channel 1	166	(= 2 + 4 + 32 + 128)
Channel 2	1	
Channel 3	0	

The configuration number for channel 1 is made up of four elements, as indicated, corresponding to:

Pulsed Helium Level operation
Autofill using the Channel Relay (i.e. Relay 1 since this is channel 1)
Alarm sounds and Relay 4 active for a LOW condition
Automatic FAST / SLOW rate switching implemented

(Refer to section 9.7 for full details of all the configuration parameter options.)

The configuration number for channel 2 corresponds to a nitrogen level indicator with no autofill or alarms implemented and the number for channel 3 corresponds to an unused channel.

We assume that the level thresholds for channel 1 are at their default settings, with LOW = 10%, FILL = 20% and FULL = 90%.

Initially we assume that the helium and nitrogen levels are both at 100%.

STATUS	MEANING
X210S040000R00	Helium & Nitrogen Operating Normally. Helium in SLOW rate.
X210S050000R00	Helium Probe Current is on for a measurement pulse.
X290S040000R00	The Nitrogen Probe has been un-plugged.
X210S040000R00	The Nitrogen Probe has been re-connected.
X210S030000R00	Helium has been switched to FAST & current is on for a pulse.
X210S020000R00	Pulse is complete. Helium remains in FAST rate.
X210S0A0000R00	Still in FAST. Level has fallen below 90% (FULL threshold).
X210S0C0000R00	Operator has switched Helium back to SLOW.

X210S1A0000R10	Level has fallen below 20% (FILL threshold). Filling has started and Relay 1 is active. Rate has automatically switched to FAST.
X210S120000R10	Level has risen above 20%. Filling is continuing.
X210S020000R00	Level has risen above 90%. Filling has stopped.
X210S040000R00	Level has not risen for 15 minutes so rate switched to SLOW.
X210S0C0000R00	Level has fallen below 90%
X210S1A0000R10	Level has fallen below 20% (FILL threshold). Filling has started and Relay 1 is active. Rate has automatically switched to FAST.
X210S7A0000R96	Fill has failed. Level has fallen below 10% (LOW threshold). ALARM lamp is lit, ALARM is sounding and Relay 4 is active.
X210S7A0000R14	Operator has pressed SILENCE button. Sound is cancelled and Relay 4 has released. Alarm lamp remains lit.
X210S1A0000R10	Filling has been resumed. Level is above 10%. Alarm lamp goes out and filling continues.
X210S120000R10	Level has risen above 20%. Filling is continuing.
X210S020000R00	Level has risen above 90%. Filling has stopped.
X210S040000R00	Level has not risen for 15 minutes so rate switched to SLOW.

9 Configuration and Test Mode

9.1 Use of Test Mode

Test mode is provided to give an easy means of testing the ILM hardware and to allow it to be configured for specific applications. Test mode gives a menu of options arranged in the logical order for testing, configuring and calibrating a new instrument.

9.2 Entering Test Mode

With the instrument operating normally, enter the TEST mode by holding the RAISE and LOWER buttons depressed, whilst pressing and releasing the SILENCE button.

The message

tSt

will appear followed shortly by:

t.00

RAISE and LOWER may now be used to select a specific test in the range 1 to 11. For example to access test 7, press RAISE seven times twice (or RAISE five times), to display:

t.07

With the required test number displayed, press and release SILENCE. The instrument will then enter that test, often displaying the first item in a further menu.

To leave test mode from the main test menu, select

t.00

When LOC/REM is pressed, normal operation will resume. (Some tests automatically return to normal operation on completion, without returning to the test menu.)

9.3 Test t.01 Testing the Display and Relays

Activating this test will light each segment in the display and each LED in sequence, followed by activating each output line on the auxiliary port in turn. If relays are fitted, they will be energised in sequence, and the internal alarm will

sound unless it has been disabled by switch S2/2. At the end of the test, the main test menu will return. (Note that if only one channel is fitted there will be a long pause between the channel 1 display being tested and the relays being energised.) This test cycles through all the hardware options, whether of not they are fitted.

9.4 Test t.02 Testing the Keys

When this test is activated nothing will be lit on the display until a key is pressed. For each key pressed, one and only one, segment of a display should light. Exit from this test by pressing RAISE, LOWER and SILENCE together.

9.5 Test t.03 Setting the GPIB Address

The GPIB interface (if fitted) is normally supplied set to a GPIB address of 24. On accessing Test 3, the display will now show G.nn where nn is the current GPIB address. Use RAISE and LOWER to display the desired new address, then press SILENCE to select it. The instrument will revert to the t.00 state. Pressing SILENCE again will restart the instrument, with the new address in operation. Any address in the range 1 to 30 may be selected. (Although 31 may be selected, it is not a valid GPIB address since it is reserved for the UNTALK, UNLISTEN functions). Setting the GPIB address to 0 has a special significance. It DISABLES the GPIB interface ensuring that only RS232 operation is possible. To ENABLE it again it is only necessary to return to the t.03 mode and select a new non-zero address.

After the address has been changed, if the new address is to be retained on power down, it must be copied into the Non-Volatile memory by means of the STORE operation (See section 4.5).

9.6 Test t.04 The Diagnostic Front Panel Display

The channel 1 display may be set to show any of the available readable parameters, for diagnostic purposes. Selecting t.04 will give a display F.00. RAISE and LOWER may be used to select a parameter to display. Allowable parameters are as described for the R and F commands in section 8. Normal operation resumes as soon as the parameter is selected, with the chosen parameter on the channel 1 display. To restore the correct display, re-enter test mode and select t.00. (Note that when the diagnostic display is in use, no channels will show the "**Err**" message, even if they have no probe connected. Note also that channel 1 must be configured as "in-use" i.e. configuration number must not be zero, to obtain a diagnostic display).

9.7 Test t.05 Configuring the Channels

The first stage in configuring an ILM for a specific application is to set a configuration number for each channel in turn. When t.05 is selected, the channel 1 display will show "**CFG**". If SILENCE is now pressed and held in, the configuration number for channel 1 will be displayed. This is a decimal number in the range 0 to 255, the meaning of which is described below. Whilst SILENCE is held, RAISE or LOWER may be used to change this number. When SILENCE is released, the channel 2 display will show "**C**". The same procedure of using RAISE and LOWER whilst holding SILENCE pressed may be used to adjust this. Finally the same process is repeated for channel 3. When SILENCE is released for the third time, the main test menu will return on the channel 1 display.

Where an instrument only has displays fitted for one or two channels, it is still necessary to step through the configuration for all three channels. Normally this just means pressing and releasing SILENCE until the "**tst**" message returns. The configuration number for the unused channels will have been set to zero during manufacture. If you suspect that it may have been set to some other value, for each unused channel, hold SILENCE pressed, then press and hold LOWER for 10 seconds. This will ensure that the value is changed to zero.

The configuration is specified by a number in the range 0 to 255. The number is made up of 4 parts, as follows. Just one option should be selected from each part. The final number is obtained by adding the numbers for the 4 parts.

OPERATING MODE

- 0 - Channel not in use
- 1 - Channel used for Nitrogen Level
- 2 - Channel used for Helium Level (Normal Pulsed Operation)
- 3 - Channel used for Helium Level (Continuous Measurement)

Action on FILL condition

- 0 - None (Just lights FILL LED)
- 4 - Activates Channel Relay (for Autofill)
- 8 - Activates Alarm & Relay 4 (SILENCE clears Relay 4)
- 12 - Activates Needle Valve Motor (If fitted)

Action on LOW condition

- 0 - None (Just lights LOW LED)
- 32 - Activates ALARM & Relay 4 (SILENCE clears Relay 4)
- 64 - Light SHUT DOWN, ALARM & Relay 4 (SILENCE disabled)
- 80 - Light SHUT DOWN & Activate Relay 1
- 96 - Light SHUT DOWN & Activate Relay 2
- 112 - Light SHUT DOWN & Activate Relay 3

Automatic FAST / SLOW Switching
0 - None (Remains in State set by Operator)
128 - Switches to FAST when FILL first lights
Switches to SLOW when level has not risen for 15 mins

It is important to set the configuration number first when setting up an ILM, since the choices offered for the later options will depend on the use for which the channel has been configured. (Do not forget to STORE the new configuration before switching off.)

9.8 Test t.06 Calibrating the Current Sources

For any channel which is configured for use with a Helium probe, it is necessary to calibrate the current source hardware so that it delivers the required current. (Note that this calibrates the hardware, it does not set the required wire current at this stage.)

When t.06 is selected the display for the first Helium channel will show "**ICAL**" and both FAST and SLOW will light, indicating that current is flowing through the probe. For this test a current meter should be connected in place of the probe. RAISE and LOWER may be used to adjust the actual current flowing through the meter till this reads 100 mA. Note that the calibration is done at exactly 100mA, **not** the actual wire current for a probe. When the current has been set, press SILENCE again. The current will be turned off and the process repeated for channel 2 if this also is to be used for Helium. Any channels configured for Nitrogen will not be included in this step. When all channels have been set, the main test menu will return. (Do not forget to STORE before switching off.)

Important - If the current source calibration is changed, the value of the probe current set in t.08 (see below) will change. Thus t.08 must be re-set to the required value **after** any change to the current source calibration.

9.9 Test t.07 Setting Probe Active Length

An essential part of the calibration of ILM is to tell the meter the active length of the probe. This is the length of the section of the probe between the 0% cryogen level and the 100% cryogen level. ILM uses this to establish an approximate default calibration in the absence of cryogen and to ensure that the accurate calibration is within the range of the 0% and 100% adjustments. For a Helium probe, where 100% always corresponds to the superconducting wire totally immersed, if an accurate figure is supplied for the active length the default calibration will be within 10% of the final value. For a nitrogen probe there will

be an indeterminate length of probe between the 100% point and the physical top of the probe. This makes predicting an accurate default calibration harder.

In some cases it may be necessary to set an "incorrect" figure for the active length in order to ensure that the 0% and 100% points can both be calibrated correctly. If the displayed reading is too low, try setting a longer active length. If it is too high, try setting a shorter active length.

When test t.07 is selected the display will show "**LEn**". Pressing and holding SILENCE will then show the nominal length in millimetres, which may be adjusted by RAISE and LOWER.

9.10 Test t.08 Setting Helium Probe Currents

Setting the wire currents for a Helium level probe follows the same procedure as above. Provided the current source(s) have been calibrated, the displayed figure is the actual pulse current in mA. Note that any changes to the calibration of the current source, will modify the value set in t.08. Hence test t.06 must be carried out **before** setting the required probe current with t.08.

ILM allows provision for setting two currents for each Helium probe. As well as the main measuring pulse, there is provision for supplying a higher current "**Pre-pulse**". This can have advantages with certain probes in unusual applications where for some reason it is difficult to initiate the propagation of a resistive region in the probe at the normal working current. Unless you have been advised otherwise by *Oxford Instruments* you should assume that your probe will not require a pre-pulse. In which case, both the pre-pulse current and the pre-pulse width should be set to zero.

When t.08 is selected the first prompt is "**PCu**", inviting entry of the pre-pulse current. After this has been set (usually to 0) the prompt "**Cur**" will appear inviting entry of the main pulse current. Typically a figure of 115mA will be used for the standard *Oxford Instruments* probes (having a resistance of 178 ohms/metre). For operation of a probe in a 1 Kelvin environment, a lower current will be required, typically 85mA.

9.11 Test t.09 Setting Helium Probe Pulse Widths

The same sequence is followed for setting the pulse width. The prompt "**PrE**" invites entry of the pre-pulse width (usually zero) and the prompt "**PUL**" invites entry of the main pulse width. Pulse widths are in seconds. Typical values are 2 seconds for a short probe, 3 to 4 seconds for a long probe. The velocity with which the resistive region propagates down the wire is approximately constant, so

that a long probe will require a longer pulse to ensure the pulse reaches the liquid surface when the reservoir is nearly empty.

9.12 Test t.10 Setting Helium Probe Sample Rates

A similar procedure is followed to set the interval between sampling pulses for the fast and slow rates. The prompts are "**FAS**" and "**SLO**" respectively. **BEWARE**, the figure for the fast rate is entered in **SECONDS**, whilst that for the slow rate is entered in **MINUTES**. This is done deliberately to reflect the normal usage of the meter and keep numbers within the working range of the display. A typical interval of 20 seconds might be used in the fast rate whilst filling a cryostat, whilst an interval of 60 minutes would be adequate to follow the rate of cryogen fall between fills, without adding any significant contribution to the cryogen consumption. Allowable settings are 1 to 1999 seconds for the fast rate and 1 to 1999 minutes for the slow rate. (Note that the indicated times are the intervals between the pulses. The pulse width and pre-pulse width should be added to these to obtain the pulse repetition interval.)

9.13 Test t.11 Setting Full, Fill and Low Thresholds

A similar procedure is again used to set the thresholds for each channel in use. The prompts for the thresholds are "**FUL**", "**FIL**" and "**LO**" respectively. Default settings are 90%, 20% and 10%.

9.14 A Final Reminder

After setting up the instrument, please remember to STORE the results before switching off or they will be lost. To STORE, press and hold any 0% or 100% key (it does not matter which) and press and release SILENCE. The channel 1 display should show "**Sto**". If it shows "**Pro**" instead, the internal switch S2/1 is in the OFF position and must be set to ON before data can be stored.

10 Servicing

10.1 Safety

This section of the manual contains information intended to help a qualified service engineer diagnose faults on the ILM. Some of the test procedures involved require operation of ILM with the covers removed. This can expose the engineer to the risk of contacting lethal voltages. Such work should only be carried out by a suitably qualified engineer who is aware of the hazards involved.

10.2 Circuit Description

The majority of the circuitry involved in ILM is conventional and can be readily understood from the circuit diagrams. The notes which follow cover those areas where some additional explanation may be required.

The circuit is divided into two isolated sections; the digital logic and the analogue probe interface. The sections have separate, isolated power supplies and signals between the two sections are transmitted by optical isolators.

The power supply for the digital circuit generates an unregulated 11 volts from which the regulated 5 volt supply is obtained. The unregulated 11 volt supply is used to monitor mains volts. Should this fall below 8 volts, a RESET is performed. (If ILM is operated on very low mains volts, it may keep resetting. This may be identified by the "**He**" or "**N2**" message reappearing during use.)

The power supply for the analogue circuits is initially regulated by U502 to produce a 45 volt stabilised rail. A +12 volt rail is derived from this via U504 and a +30 volt rail is derived via U503. Note that this rail is stabilised as 15 volts below the +45 volt rail. The input to U503 and U504 is held at approximately 27 volts below the +45 volt rail by D501.

Separate analogue probe interface circuits are provided for each channel. Components will only be fitted for the probe 2 and 3 interface circuits on 2 and 3 channel instruments. Channels 1 and 2 both have provision for a current source to drive a Helium probe. Channel 3 may only be used for a Nitrogen probe and has no current source. The description which follows applies to channel 1. Component references for the other channels follow a logical relationship to those for channel 1 with numbers in the 200's and 300's respectively.

The current source for the Helium probe is fed from the +45V rail via the sense resistor R101 and power transistor Q101. The current delivered is controlled by the voltage at the + input of U101. This is determined by a variable duty cycle waveform from the microprocessor fed via opto isolator U102 and buffer U101, with C102 and C103 forming a low pass filter whose output is the mean value of the waveform.

When a Helium probe is in use, the probe voltage is filtered and fed to the V/F convertor U120. This generates a frequency in the range 5kHz to 65kHz for normal probe operation, which is fed via opto-isolator U121 to the digital circuitry where it is counted. The reference voltage for U120 is fed via the V_{LOW} to I_{LOW} link in the probe. This ensures that if the probe is unplugged, the V/F oscillator stops, allowing an error condition to be detected.

When a nitrogen probe is in use, the V/F convertor is not used and the frequency from the probe itself is fed to U121, via R125. Again in the absence of a probe, a frequency of zero will be detected as an error condition.

The nitrogen probe itself employs an oscillator using the probe capacitance to govern its frequency. Oscillator components are chosen such that the frequency is within the range 5kHz to 65kHz for any probe length within the working range of the instrument. The probe output frequency is fed via a low pass filter R4, C2 to reduce the risk of high frequency harmonics being radiated from the cable. (A shielded cable should be used for both helium and nitrogen probes, to reduce both radiation and the risk of interference pick up.)

The microprocessor circuit is conventional and incorporates CPU, EPROM, RAM, CTC and USART chips. The keyboard and display are mapped directly as i/o ports on the microprocessor bus and the CPU handles all the display decoding and multiplexing in software. Analogue inputs are measured as frequencies by the CTC. Note that for the Helium level probe, level is related to (Constant - Frequency) whereas for the Nitrogen level probe, level is related to (Constant / Frequency). This difference is handled automatically by the microprocessor maths, depending upon the probe type for which a channel is configured. Calibration data and configuration data which is to be stored at power down is held in an EEPROM and this is only written to as part of the "STORE" operation.

10.3 Reset Procedures

10.3.1 Entry to Test Mode

ILM performs a basic self test of the microprocessor and memory at switch on, before displaying the "**He**" or "**N2**" message. A more detailed hardware test mode is available for help during fault finding. This has already been described in section 9. In that section, entering test mode from the front panel was described. This route may not work under certain fault conditions. An alternative method of entering the test mode, is by pressing the internal RED RESET button S1 on the main circuit board. Provided the basic CPU and memory are operational, this route will always access the test mode. The use of test mode to check the display and key hardware has been described earlier in Section 9.

10.3.2 Two Button Reset

The main RAM content is always restored from the EEPROM at switch on, so that in many cases it may be possible to recover from problems by simply switching off and switching on again. If this fails to correct the problem, bad data may have been written to the EEPROM. In this case a two button reset may be carried out by holding the RAISE button pressed, whilst pressing and releasing the internal RED button S1 on the main PCB. This partially resets the RAM content and will always restore a "**He**" or "**N2**" message and a normal display if no other faults are present.

10.3.3 Three Button Reset

If the EEPROM content is completely corrupted, of if a new EEPROM has been fitted it will be necessary to carry out a three button reset. This completely initialises the entire memory, setting default values for all variables and wiping out any previous configuration and calibration data. It is carried out by holding both RAISE and LOWER pressed whilst pressing and releasing S1 on the main PCB.

Provided a STORE operation is not performed, the EEPROM will not be re-written by either a two or three button reset so these resets can be used as safe diagnostics. (**N.B. This is not the case with ITC4 or some other OI instruments.**) If a reset cures the problem, STORE may then be used in the normal way to write the new RAM content to EEPROM.

11 *In Case of Difficulty*

This section indicates some of the more common pitfalls and operator errors.

Display shows "Err" in normal use
No probe is plugged in to the channel, or the probe is defective. In the case of a nitrogen probe, it may have been shorted out by water or ice. Try removing the probe and drying it thoroughly.

RATE, RAISE, LOWER etc. appear not to work
A computer has taken control by issuing a "C1" command

"S.nn", "G.nn", "He" or "N2" message appears during operation
Low mains voltage. ILM is resetting. Check mains voltage setting is correct.

Cannot get 0% & 100% calibration correct together
The nominal Active Probe Length has been set incorrectly.

Display shows "Err" after adjusting either 0% or 100%
The nominal Active Probe Length has been set incorrectly.

Configuration, Calibration or Level Thresholds lost after Power Down
The STORE operation has not been performed after calibrating, setting limits etc. (see section 4.5).

No Display or Abnormal Display (e.g. Multiple Decimal Points)
This probably indicates a hardware defect but can occasionally be due to corruption of RAM content. The first action should be to switch ILM off and on again. This will reload the RAM from the EEPROM. If this cures the problem and it does not recur the RAM had probably been corrupted by a supply glitch or injudicious use of the "Y" command. If it fails to cure the problem the EEPROM content may be corrupt. Try the reset procedures described in section 10.3. If the problem recurs, a hardware fault in the microprocessor or RAM is indicated.

12 Specification

CHANNELS	1, 2 or 3
ILM201	1 x Nitrogen
ILM210	1 x Helium
ILM211	1 x Helium, 1 x Nitrogen
ILM220	2 x Helium
ILM221	2 x Helium, 1 x Nitrogen
SENSING METHOD	
Helium	Superconductive Wire
Nitrogen	Capacitance
PROBE LENGTH	
Helium	1 metre (standard wire)
Nitrogen	2 metres
PROBE CURRENT (Helium)	115 mA Typ, (199 mA Max pulsed)
PULSE WIDTH (Helium)	Adjustable 1 second to continuous
PROBE RESISTANCE (Helium)	178 ohms / metre (standard wire)
VOLTAGE COMPLIANCE (Helium)	40 volts
SAMPLING INTERVAL (Helium)	1 to 1999 seconds (FAST) 1 to 1999 minutes (SLOW)
PROBE CAPACITANCE (Nitrogen)	130 pF / metre (typical)
DISPLAY TYPE	0.56 inch red LED
DISPLAY RANGE	-1.0% TO +101.0%
AUTOFILL CONTROL	Open Collector logic output Internal Relay (optional) Stepper Motor Drive (One channel)
AUTOMATIC SHUT DOWN	Open Collector logic output Internal Relay (optional)
ALARM	Internal Audible Alarm Open Collector Logic o/p Internal Relay (optional)
RELAY CONTACT RATING	240 V AC, 5 A (Where fitted)

RS232 INTERFACE	Configured as DCE
HANDSHAKE	None Required
BAUD RATE	9600 Baud
IEEE-488 INTERFACE	Optional Internal Interface
ADDRESS RANGE	1 to 31
CAPABILITY IDENTIFICATION CODE	SH1 AH1 T6 L4 SR1 RL0 PP0 DC1 DT0 C0 E1
CONNECTORS	
POWER IN	IEC 3 pin
PROBE INPUT	3 off 9 way D socket
AUXILIARY I/O	15 way D socket
RS232	25 way D socket
GPIB	Standard Connector, if fitted
POWER REQUIREMENTS	100-240V 50/60Hz
POWER CONSUMPTION	60VA approx
CASE STYLE	Freestanding Metal Case Optional Rack Mount Ears
DIMENSIONS	
FREESTANDING	446mm x 106mm x 298mm
RACK MOUNT	19 inch x 2U x 298mm
WEIGHT	6.0kg

13 *Quick Reference Guide*

Panel Controls and Lamps

RATE	Toggle between FAST and SLOW. Sample immediately on entry to FAST. (Helium Level Only).
FAST/SLOW	Light to show FAST or SLOW sampling rate. BOTH lit during pulse. (Helium Level Only).
0%	Calibrate reading near zero, using RAISE and LOWER.
100%	Calibrate reading near full scale, using RAISE and LOWER.
0% & 100%	Press together to set default calibration for probe length.
FILL	Lit during auto-filling. Lights when level falls below FILL threshold. Goes out when level rises above FULL threshold.
LOW	Lit when level below LOW threshold.
SHUT DOWN	Lit when Automatic Magnet Run Down initiated.
ALARM	Lit during alarm state. Alarm sounds on entry to alarm state.
SILENCE	Cancels alarm sounder. ALARM lamp remains lit until alarm condition is cleared. (Also used to select functions in TEST).
RAISE/LOWER	Used to adjust calibrations and thresholds and to select menu items in TEST.
STORE	To STORE calibration, thresholds etc.: Press and hold any 0% or 100% and press and release SILENCE.
TEST	To enter TEST and CONFIGURATION mode: Press and hold RAISE and LOWER and press and release SILENCE.

Serial / GPIB Commands

Cn	Set Local / Remote **C**ontrol C0 Local Control C1 Computer Control, Front Panel Disabled C3 Computer Control, Front Panel Enabled
Fnn	Select **F**ront Panel Ch1 Diagnostic Display. (nn as for t.04 in "Test Mode Menu")
Gnnn	Set Needle Valve position
Qn	Set Communication Protocols Q0 Normal Q2 Send <LF> after every <CR>
Rnn	Send **R**eading for parameter nn. (nn as for t.04 in "Test Mode Menu").
Sn	Set Channel n to **S**low sample rate
Tn	Set Channel n to Fas**T** sample rate
Unnnnn	**U**nlock for memory load etc. (See manual)
V	Send **V**ersion
Wnnnn	**W**ait nnnn mS before each character sent
X	E**X**amine Status. (See below for response format)
Yn	Load new content into ILM RAM. (Use with care, wipes all existing calibration. See Manual).
Zn	Dump ILM RAM content via interface. (See Manual).

Interpreting the Status Message

The response message to the "X" (**EX**amine Status) command has the form:

XabcSuuvvwwRzz

Where abc are three digits defining **Channel Usage** as:

0	Not in Use
1	Nitrogen Probe
2	Pulsed Helium Probe
3	Continuous Helium Probe
9	Error, probe not connected

and where uu, vv and ww are pairs of Hexadecimal digits defining **Channel Status**. Each pair represents an 8 bit, binary number, where the bits have the following significance (Bit 0 is LS bit):

Bit 0	Current flowing (Including pre-pulse)	
Bit 1	In FAST rate	
Bit 2	In SLOW rate	
Bits 3,4	Auto-Fill Status	
00	End Fill	(LEVEL >= FULL)
01	Not Filling	(FULL < LEVEL <= FILLING)
10	Filling	(FULL < LEVEL <= FILLING)
11	Start Fill	(LEVEL < FILL)
Bit 5	Low Active	(LEVEL < LOW)
Bit 6	Alarm Active	(As defined by CONFIG BYTE)
Bit 7	Pre-Pulse Current Flowing	

and where zz is a pair of Hexadecimal digits defining **Channel Status**. They represent an 8 bit, binary number, where the bits have the following significance (Bit 0 is LS bit):

Bit 0	In Shut Down state	
Bit 1	Alarm Sounding	(Relay 4 Active)
Bit 2	In Alarm State	(Sound may have been SILENCED)
Bit 3	Alarm SILENCE prohibited	
Bit 4	Relay 1 Active	
Bit 5	Relay 2 Active	
Bit 6	Relay 3 Active	
Bit 7	Relay 4 Active	(Duplicates bit 1)

Test Mode Menu

t.00 Resume Normal Operation

t.01 Test LEDS and RELAYS

t.02 Test KEYS (RAISE, LOWER and SILENCE together to quit)

t.03 Set GPIB Address (If GPIB Interface is fitted)

t.04 FRONT PANEL Diagnostic Display MENU (On Channel 1 Display)

- F.00 Normal Display (Same as F.01)
- F.01 Channel 1 Level
- F.02 Channel 2 Level
- F.03 Channel 3 Level
- F.04 Unused (Normal Display)
- F.05 Unused (Normal Display)
- F.06 Wire Current Channel 1
- F.07 Wire Current Channel 2
- F.08 Unused (Normal Display)
- F.09 Unused (Normal Display)
- F.10 Needle Valve Position (If used)
- F.11 Channel 1 V/F Frequency * 1/40
- F.12 Channel 2 V/F Frequency * 1/40
- F.13 Channel 3 V/F Frequency * 1/40

t.05 CONFIGURE "CFG" each Channel in turn. Specified by a number in the range 0 to 255, made up of 4 parts. The configuration number is obtained by adding the 4 parts.

Operating MODE

- 0 Channel not in use
- 1 Channel used for Nitrogen Level
- 2 Channel used for Helium Level (Normal Pulsed Operation)
- 3 Channel used for Helium Level (Continuous Measurement)

Action on FILL condition

- 0 None (Just lights FILL LED)
- 4 Activates Channel Relay (for Autofill)
- 8 Activates Alarm & Relay 4 (SILENCE clears Relay 4)
- 12 Activates Needle Valve Motor (If fitted)

Action on LOW condition

0	None (Just lights LOW LED)
32	Activates ALARM & Relay 4 (SILENCE clears Relay 4)
64	Light SHUT DOWN, ALARM & Relay 4 (SILENCE disabled)
80	Light SHUT DOWN & Activate Relay 1
96	Light SHUT DOWN & Activate Relay 2
112	Light SHUT DOWN & Activate Relay 3

Automatic FAST / SLOW Switching

0	None (Remains in State set by Operator)
128	Switch to FAST when FILL lights. Switch to SLOW when no rise for 15 mins.

t.06 Calibrate Internal Current Source, "ICAL"
Sets current demand to 100mA. Use RAISE and LOWER to adjust actual delivered current to this value. Applies to any channel Configured for Helium use.
(Must reset t.08 value after any changes to t.06)

t.07 Set nominal Active LENGTH for probe. (Probe calibration will not be possible if length is not approximately correct).

t.08 Set wire currents for Pre-Pulse "PCu" (Normally not used) and Measuring Pulse "Cur". Units are mA. Current source must be calibrated by t.06, before setting t.08.

t.09 Set pulse widths for Pre-Pulse "PrE" (Normally set to 0 to disable pre-pulse) and measuring pulse "PUL". Units are sec.

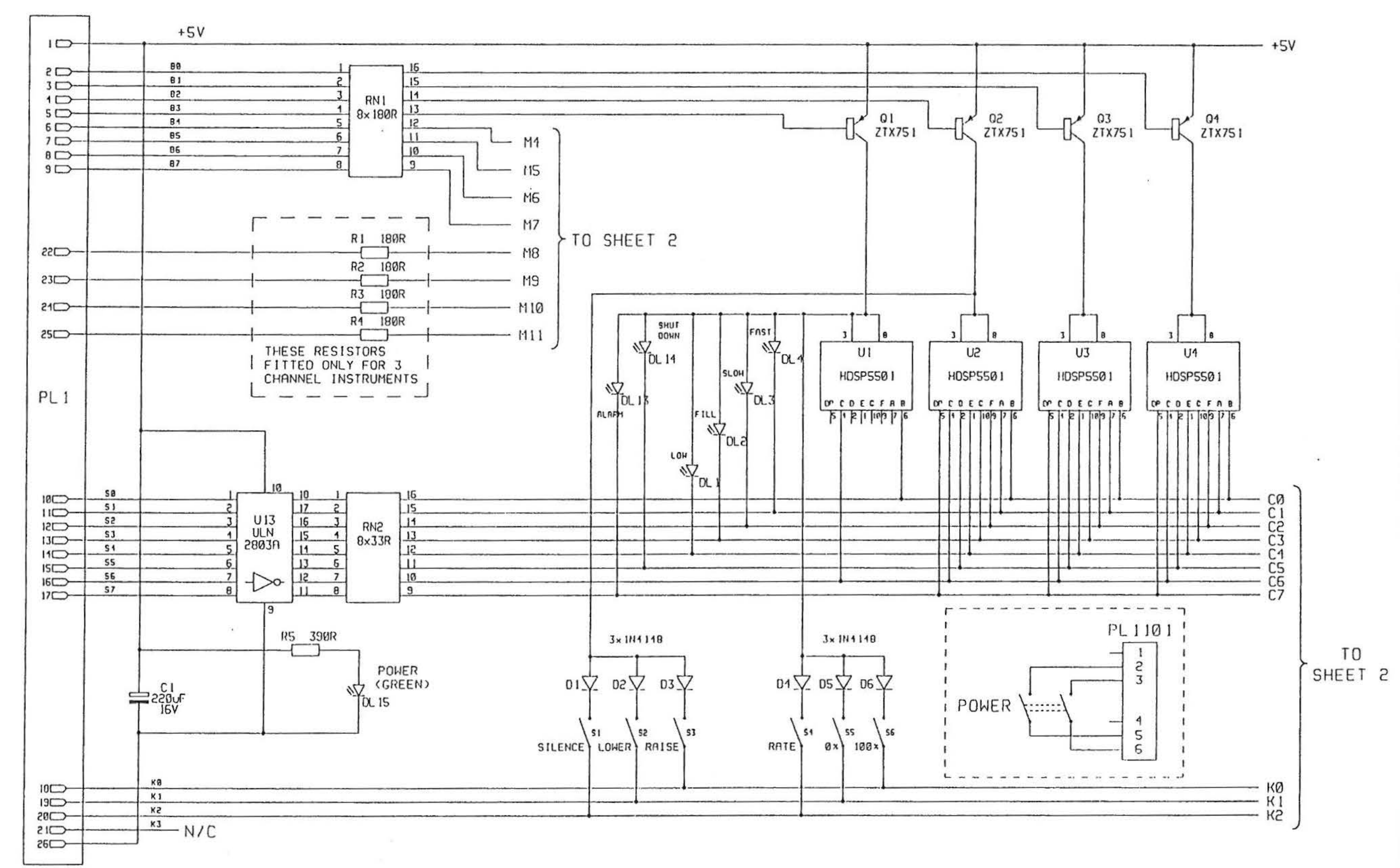
t.10 Set intervals between pulses in FAST and SLOW.
Note that Units are Seconds for FAST and Minutes for SLOW.

t.11 Set thresholds for FULL (Filling stops), FILL (Filling starts) and LOW.

14 Circuit Diagrams

The following circuit diagrams are included, covering ILM itself, together with its accessories:

CNC0102	(2 sheets)	DISPLAY BOARD
CNC2002	(7 sheets)	MAIN BOARD
CNC5102	(1 sheet)	NITROGEN PROBE
CNC5202	(1 sheet)	HELIUM PROBE
CVA0002	(1 sheet)	OXFORD ISOBUS CABLE
CVG0102	(1 sheet)	GPIB INTERFACE



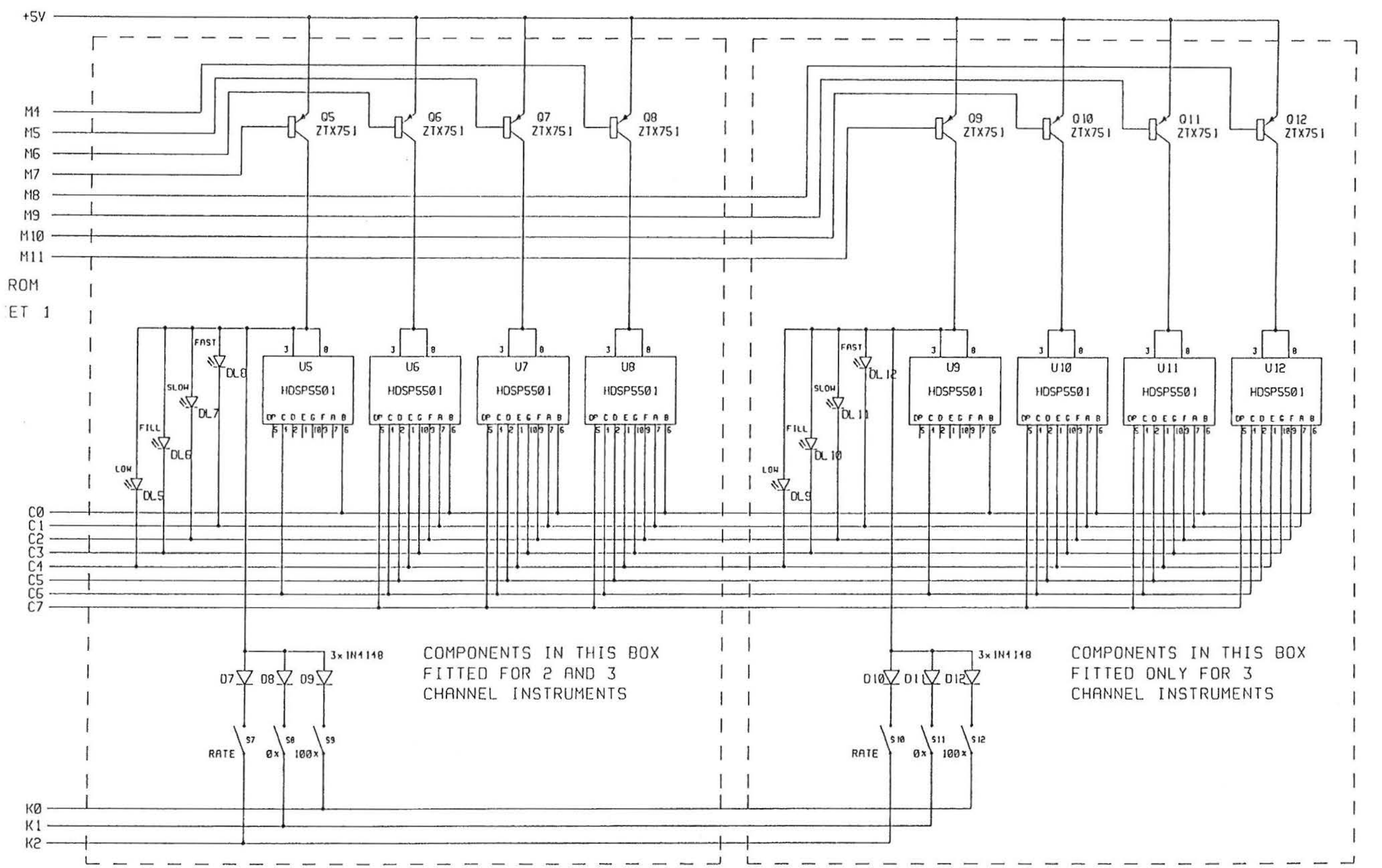
28/3/94	U13 LABEL CORRECTED
27/10/93	FIRST ISSUE

TITLE

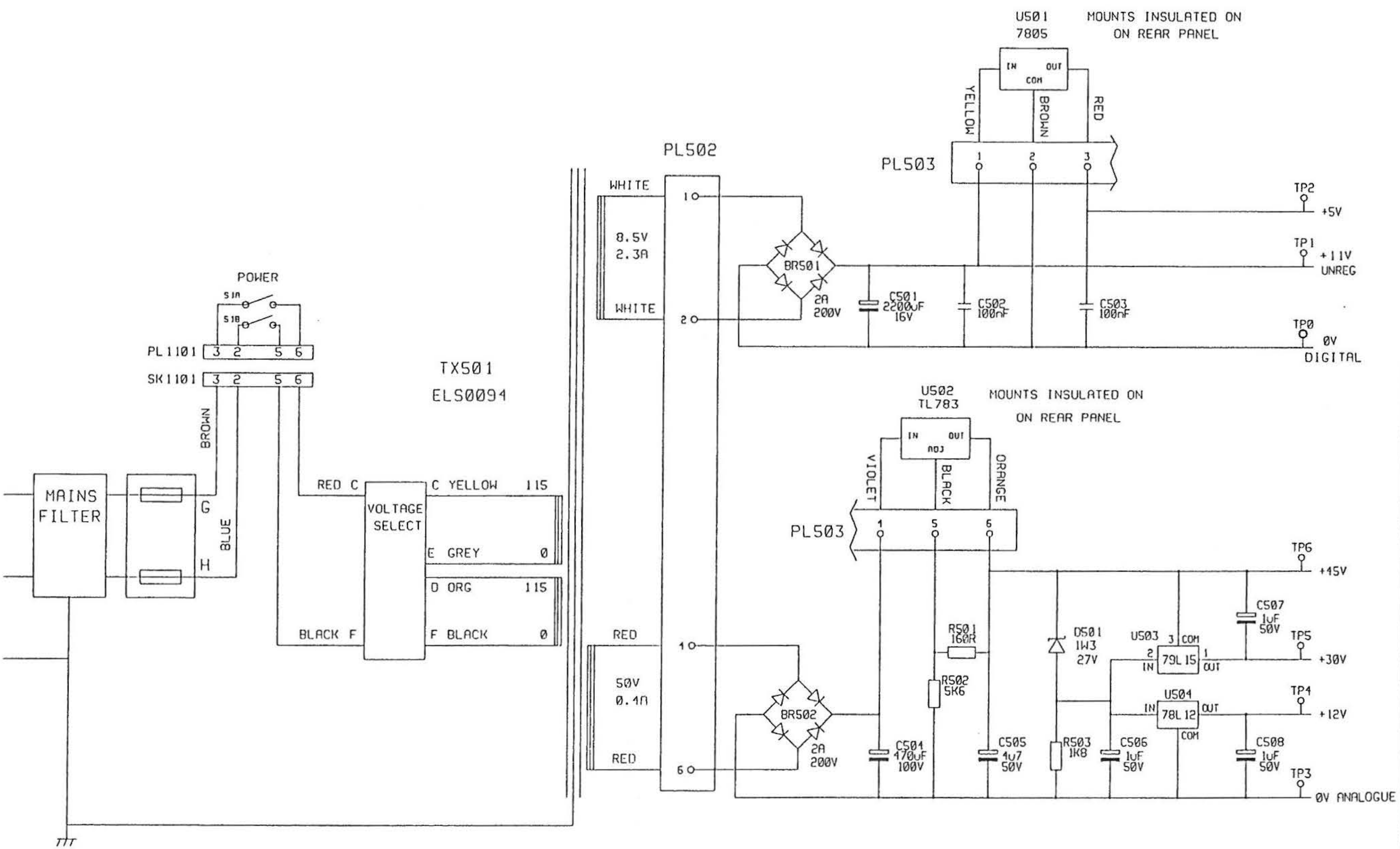
DISPLAY PCB
ILM

OXFORD

DRAWING NUMBER
A4 CNC 1002 1 of 2



28/3/94	(NO CHANGES ON SHEET 2)	TITLE: DISPLAY PCB ILM
27/10/93	FIRST ISSUE	OXFORD — DRAWING NUMBER A4 CNC1002 2 of 2



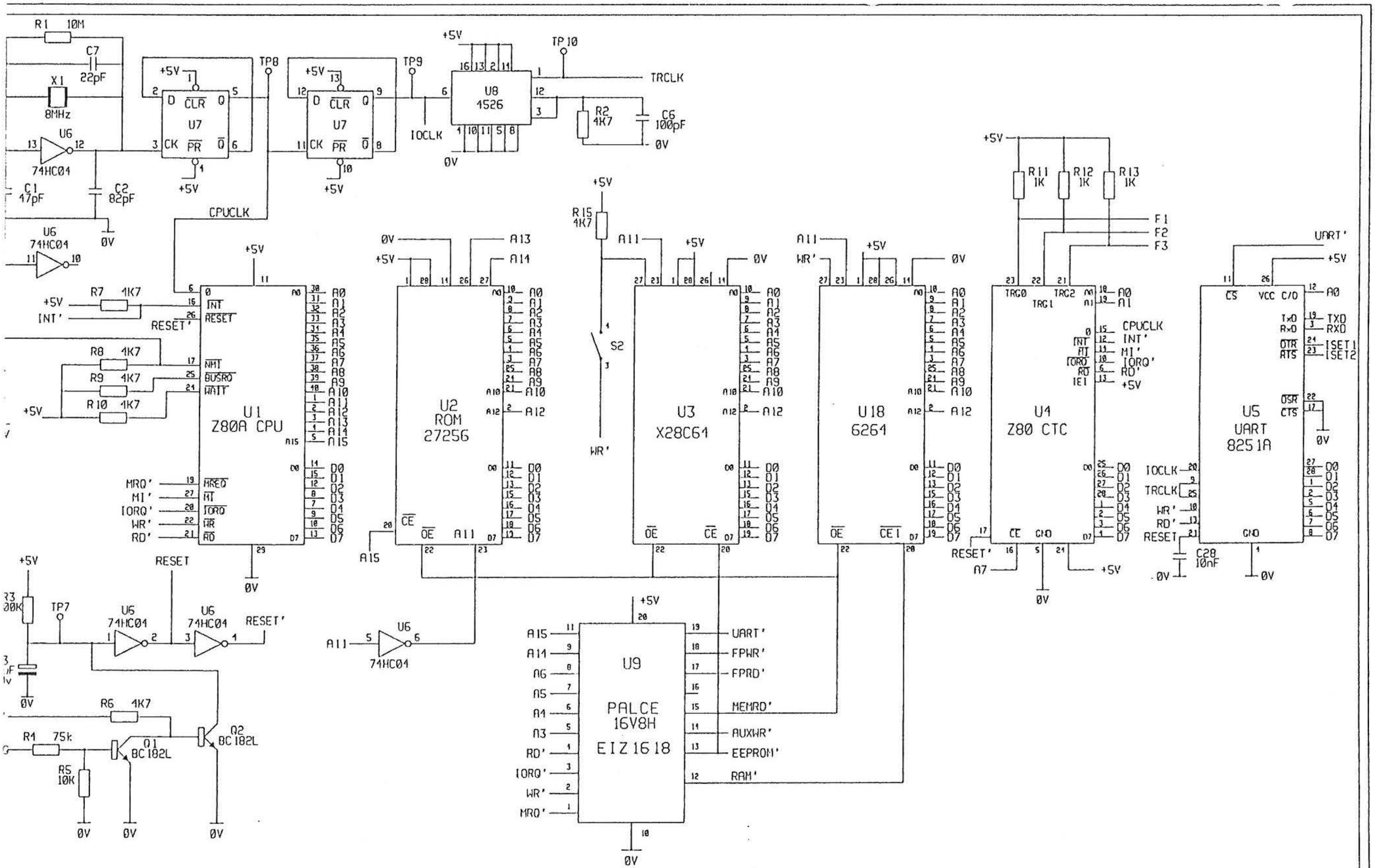
24:11:93	FIRST ISSUE	

TITLE

ILM MAIN PCB
POWER SUPPLIES

OXFORD

DRAWING NUMBER
A4 CNC2002 1 of 7



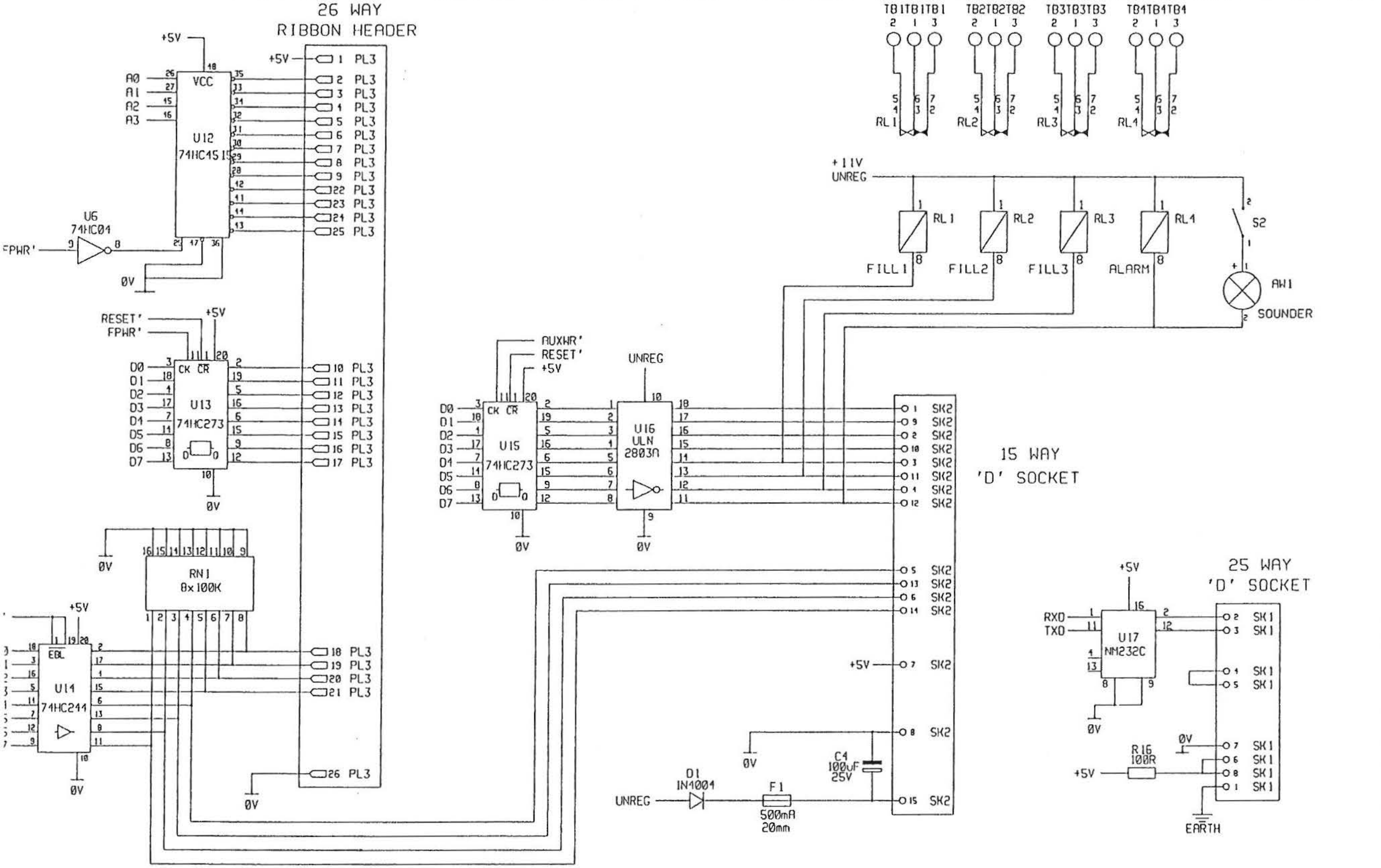
24:11:93	FIRST ISSUE

TITLE

ILM MAIN PCB
CPU/DIGITAL CONTROL

OXFORD

DRAWING NUMBER
A4 CNC2002 2 of 7



24:11:93	FIRST ISSUE

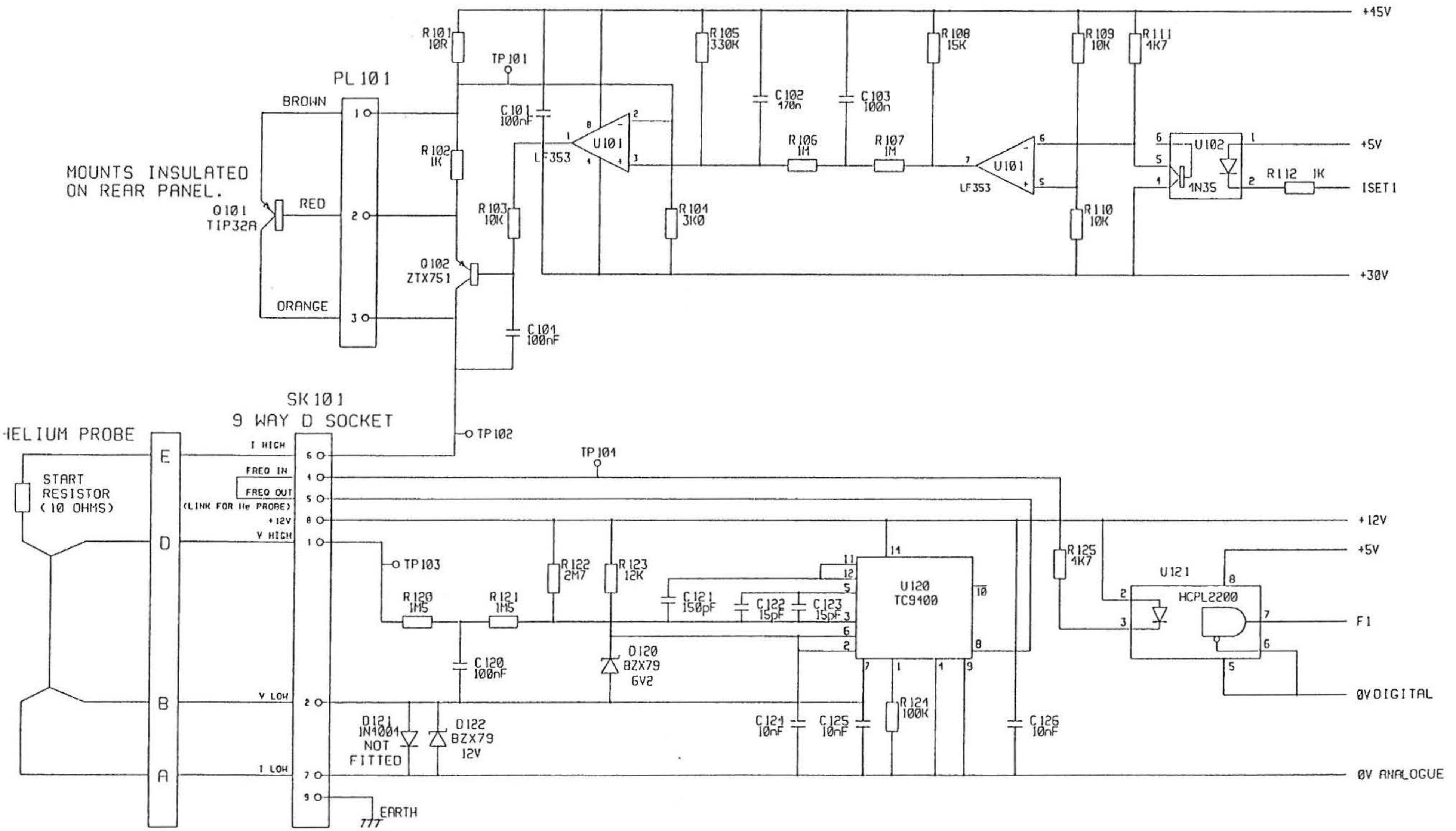
TITLE

ILM MAIN PCB
DIGITAL CONTROL

OXFORD

DRAWING NUMBER

A4 CNC2002 3 of 7



24:11:93	FIRST ISSUE

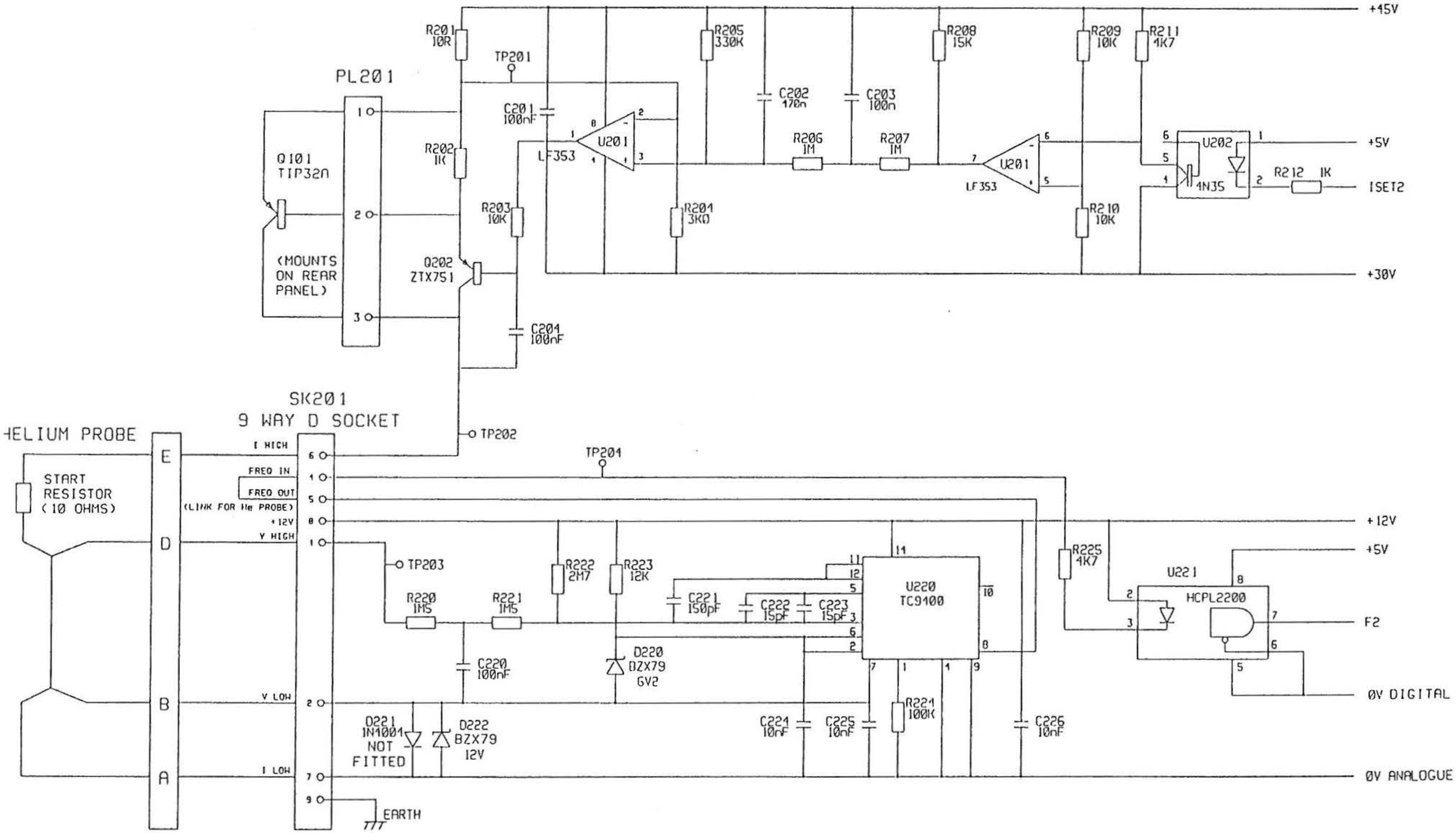
TITLE

ILM MAIN PCB
PROBE 1 INTERFACE

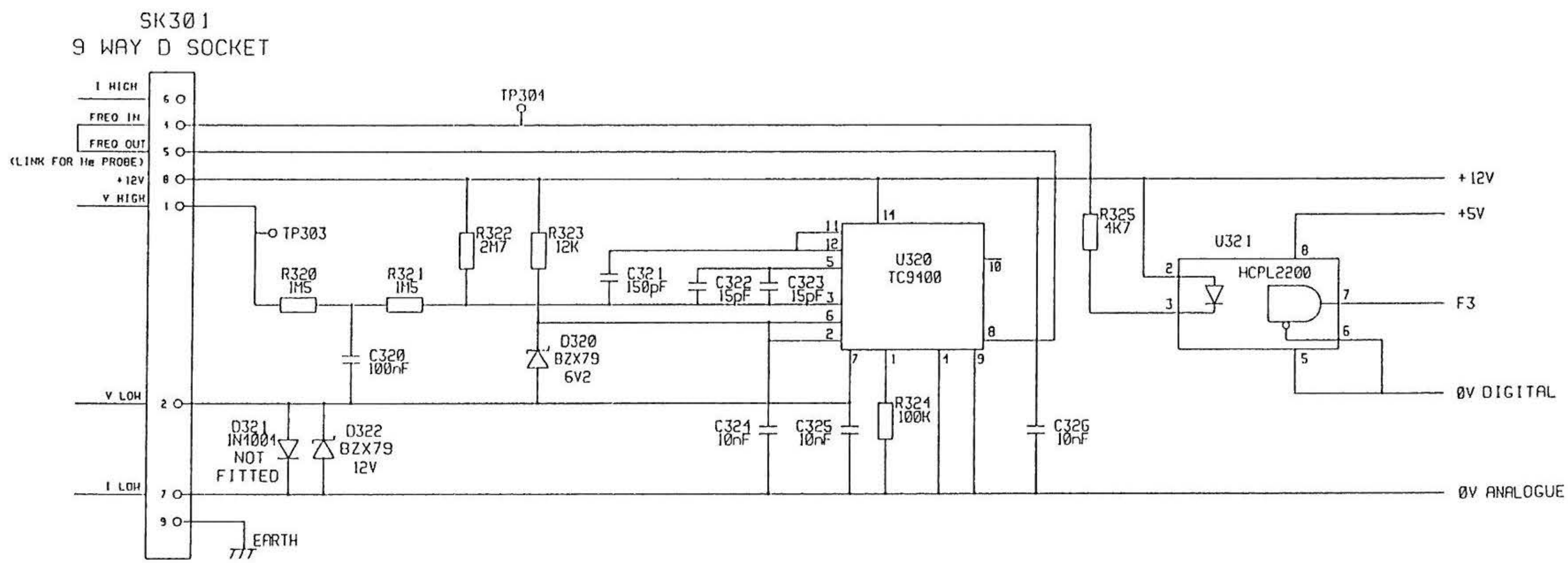
OXFORD

DRAWING NUMBER

A4 CNC2002 4 of 7



		TITLE		
24:11:93	FIRST ISSUE	ILM MAIN PCB PROBE 2 INTERFACE	OXFORD DRAWING NUMBER A4 CNC2002	5 of 7



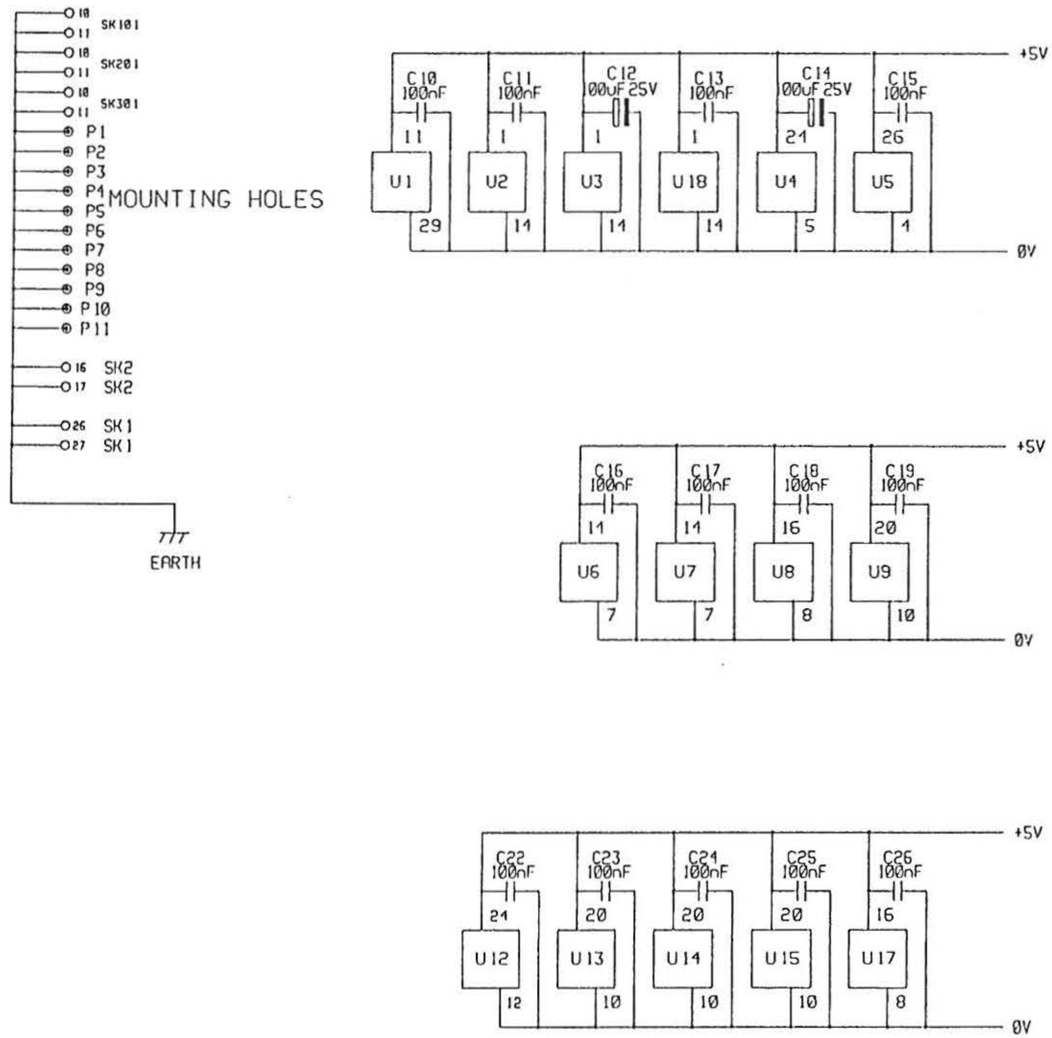
24:11:93	FIRST ISSUE

TITLE

ILM MAIN PCB
PROBE 3 INTERFACE

OXFORD

DRAWING NUMBER
A4 CNC2002 6 of 7

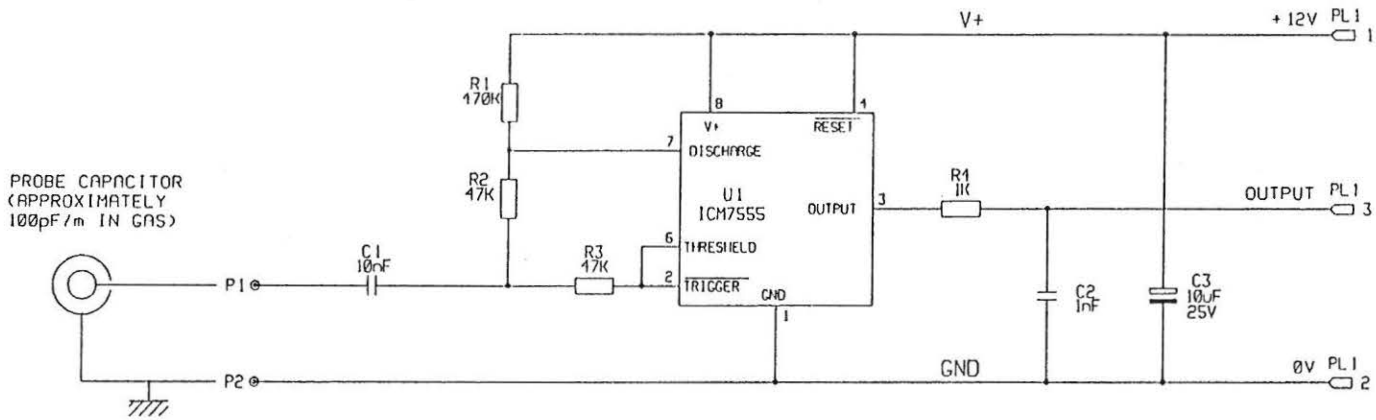


DECOUPLING CAPACITORS TO BE CLOSE TO THE RELEVANT COMPONENT.

24:11:93	FIRST ISSUE	TITLE: ILM MAIN PCB DE-COUPLING

OXFORD

DRAWING NUMBER A4 CNC2002 7 of 7



28:3:94	PL1 PIN NUMBERS ASSIGNED
13:01:94	ORIGINAL

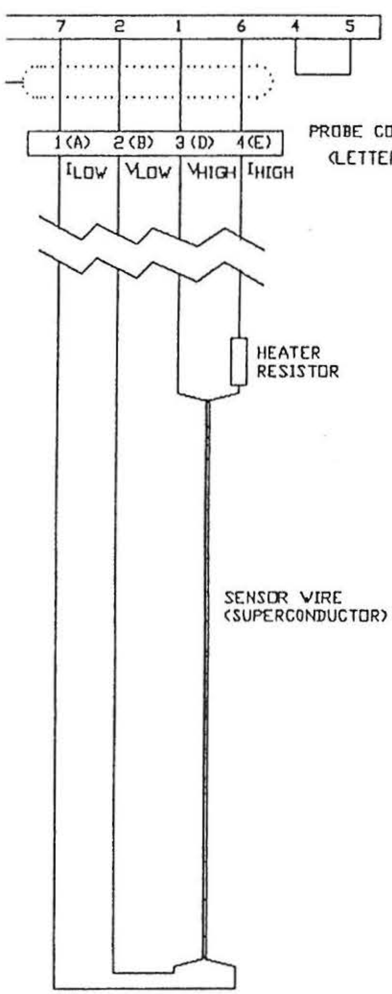
TITLE

ILM NITROGEN PROBE HEAD PCB

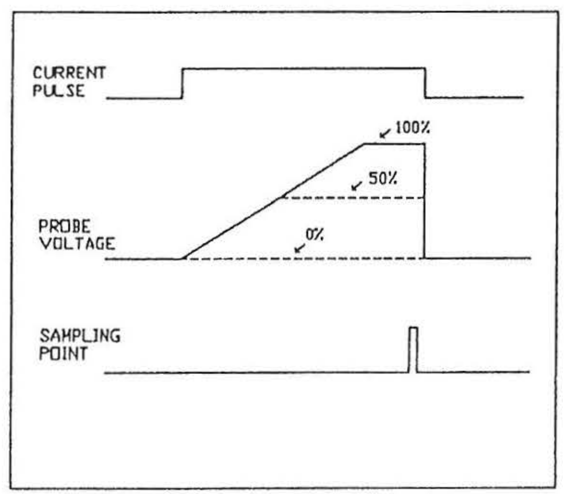
OXFORD

DRAWING NUMBER

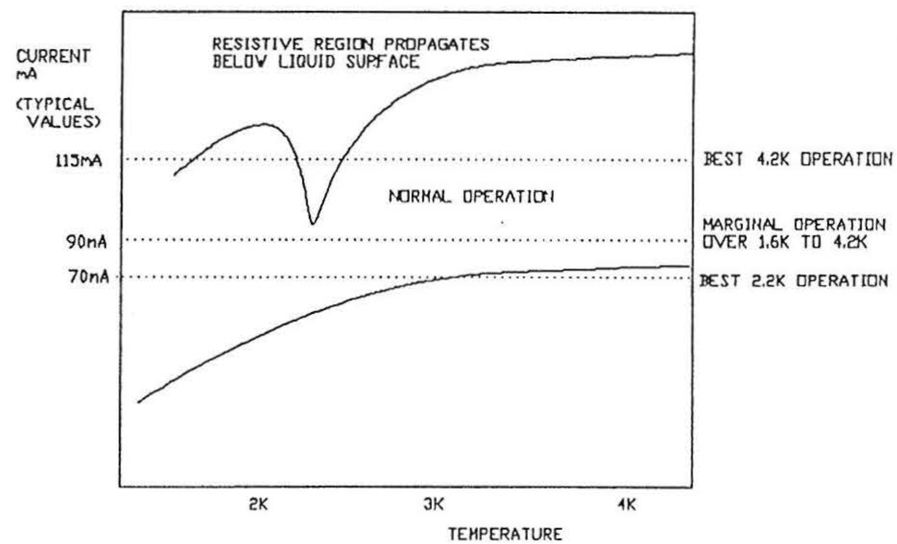
A4/CNC5 102 sht 1 of 1



PROBE I & V AS A FUNCTION OF TIME



OPERATING CURRENT AS A FUNCTION OF TEMPERATURE



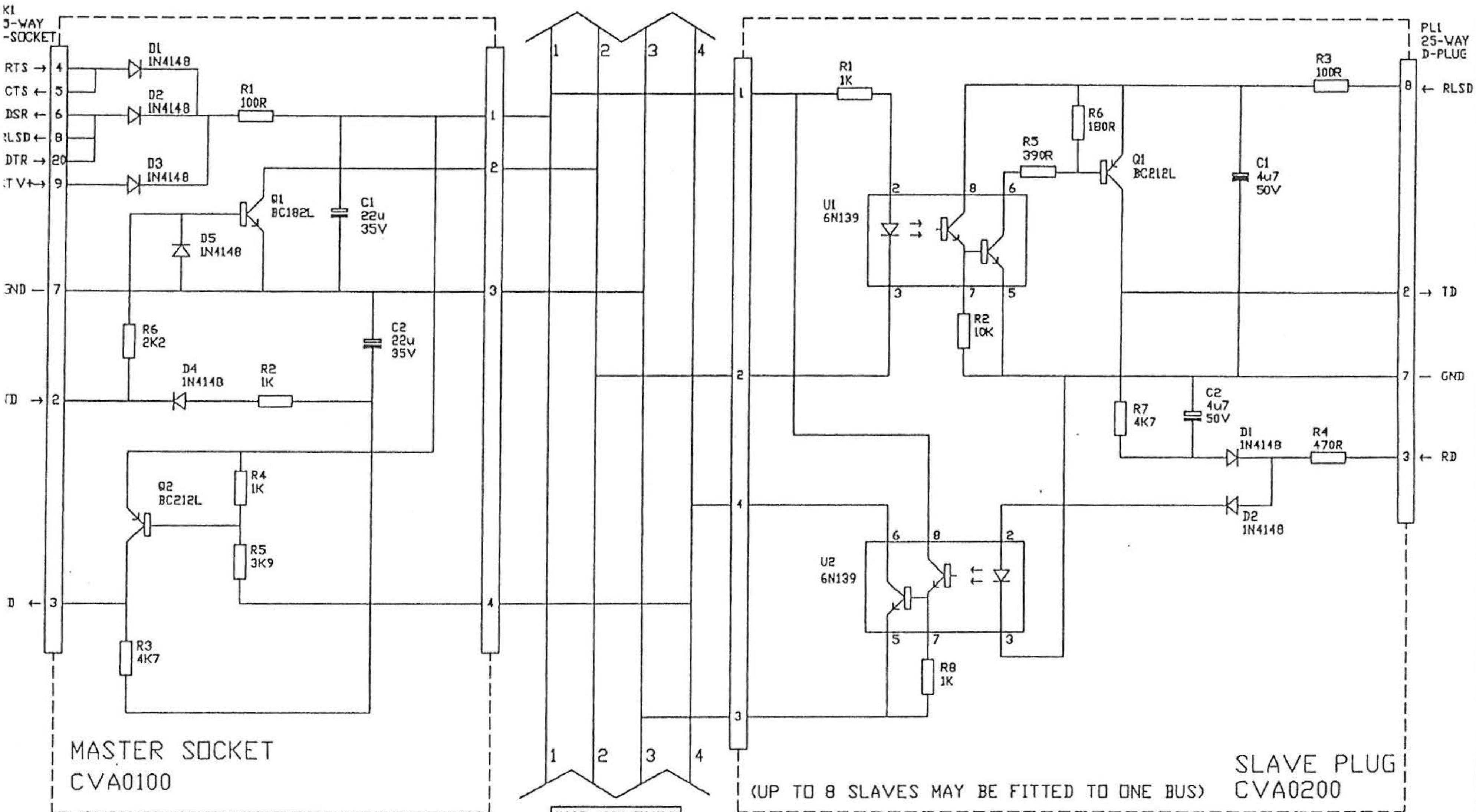
1	28/03/94	AFS	ORIGINAL	

ILM HELIUM PROBE

OXFORD

DRAWING NUMBER

A4/CNC5202



BUS COLOURS

1	V+	RED
2	TD	BLUE
3	GND	BLACK
4	RD	YELLOW

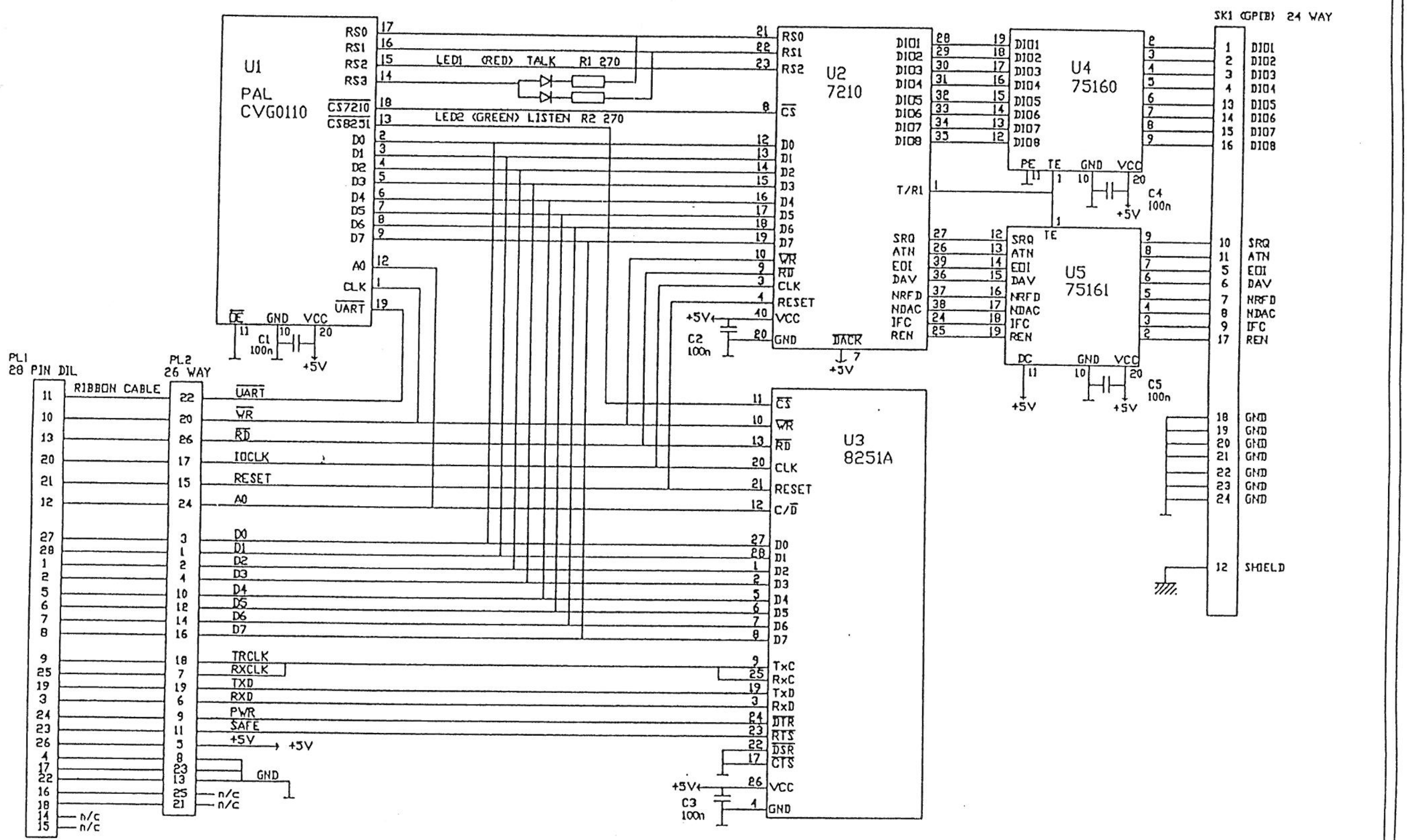
4	26/7/93	AFS	C1 CONNECTIONS CORRECTED. U1, U2 IDENTIFIER ADDED.
3	21/6/93	AFS	REDRAWN

OXFORD ISOBUS CABLE

OXFORD

DRAWING NUMBER

A4/ CVA0002



3	16/3/93 AFS	LED 1 & 2 POLARITY REVERSED, U5 PIN NUMBERING CORRECTED
2	16/2/93 AFS	PL2 RENUMBERED
1	29/1/93 AFS	ORIGINAL

GPIB INTERFACE

OXFORD

DRAWING NUMBER

A4/ CVG0102

Superconducting Magnet Power Supply
PS180-20 (180 amps, 20 volts)

Operator's Handbook

Oxford Instruments
Scientific Research Division
Old Station Way, Eynsham
Witney, Oxon, OX8 1TL, England
Telephone: (01865) 882855
Fax: (01865) 881567
Telex: 83413

Applies to Firmware Version PS2.82

Issue 1

March 1993

File reference: CBJ1.MAN

CONTENTS

1 SAFETY

The following general safety precautions must be observed during the operation, service and repair of this instrument.

1.1 Protective Ground

To minimise shock hazard the instrument must be connected to an electrical ground. The ground wire (green/yellow) in the instrument AC power cable must be connected to the installation electrical ground system. Do not use extension cords without a protective earth conductor. Do not disconnect the protective ground inside or outside the instrument. Do not have external circuits connected to the instrument when its protective ground is disconnected.

1.2 Repair and Adjustment

Ensure that the instrument is disconnected from the AC power supply (switching off the front panel POWER switch is not sufficient) before the covers are removed or fuses are replaced, otherwise dangerous voltages are accessible. For fault finding and calibration the AC power supply may require reconnection. This work may only be carried out by skilled personnel who are aware of the hazard involved.

2 *INTRODUCTION*

2.1 *Use of this Manual*

This manual provides operating and service information for the Oxford Instruments Power Supply Model PS180-20. Sections 1-4 provide essential information and should be read before operating the instrument for the first time. The remainder of the manual provides more detail on specific aspects and may be referred to as required.

2.2 *Description of Equipment*

The PS180-20 power supply is designed for energising and de-energising superconducting magnets. The supply delivers a maximum current of 180 Amps at a voltage up to +20 Volts for magnet energisation. For de-energisation it is able to absorb energy at -20 Volts. The polarity of the current in the power supply can be switched, allowing magnets to be energised in a forward or reverse direction. A separate output for a switch heater is provided for magnets incorporating superconducting switches. Remote computer control of all power supply functions can be performed via an RS232 interface.

3 *INSTALLATION*

To avoid overheating, ensure that there is sufficient space for air-flow around the power supply. There **must** be a gap of at least 100mm behind the unit.

3.1 *Supply Connection*

A three phase mains supply is required for the power supply. Before connecting the supply, ensure that the voltage label on the unit indicates the correct supply voltage. If the supply voltage is incorrect, refer to section 3.3.

Once the supply is connected, the three pole miniature circuit breaker (MCB) on the rear panel should be left in the "on" or up position. The front panel switch marked ON/OFF is then used to turn the unit on and off.

3.2 *Magnet Connections*

Connections to the main magnet current terminals are made via the large positive and negative terminals on the rear panel (M10 studs). A suitable 180 amp rated cable (normally supplied with the magnet), should be used. On no account should these connections be made or broken unless both the voltmeter and the ammeter on the power supply are at zero. When making the connections, the power supply should be switched off to ensure that bank leakage does not cause an output voltage. The small red and black terminals on the rear panel provide connections to the heater of the superconducting switch on the magnet, if fitted.

3.3 *Changing Supply Voltage*

The power supply is normally supplied set for the correct supply voltage. The high current wiring is set to operate on one of two voltage ranges, described below. The control circuits are always supplied (internally) by voltages in the range 200 to 240 volts.

i) Delta connection for "American" voltages.
Three live wires, no neutral, one earth.
Phase to phase voltage typically 208 to 230 volts a.c.
Control circuits powered Phase-to-Phase.

ii) Star connection for "European" voltages.
Three live wires, one neutral, one earth.
Phase to phase voltage typically 380 to 415 volts a.c.
Control circuits powered Phase-to-Neutral.

Setting the power supply voltage range (American or European) requires a good deal of re-wiring. It is not recommended that this is attempted by the user, the power supply should be returned to Oxford Instruments.

To alter the power supply within a voltage range is not difficult and the procedure described below should be followed.

a) Ensure that the unit is completely disconnected from the supply before starting work. Remove all rear panel connections. A rack mounted power supply should then be removed from the rack. Remove the wrap-round cover.

b) Remove the four screws and the cover from the mains voltage assembly (CBD1600). By adjusting the six links, 1,2,3,4,5 & 6 select the required voltage. Check that F3, F4 and F6 are correctly rated for this voltage range and change them if necessary. Replace the mains voltage cover.

Mains Voltage	Link 1	2	3	4	5	6
200V	A	B	B	A	B	B
220V	B	B	B	A	B	B
240V	B	B	B	B	B	B

The fuse ratings are:

F1 & F2	F3 & F4	F5
6A3 Type T	500mA Type T	50mA Type T

c) Replace the cover on the power supply (return it to its rack) and reconnect at the new supply voltage.

3.4 Cooling Water Connections

The high stability version of the PS180-20 requires connection to a continuous supply of cooling water (see section 9, Specification).

3.5 Serial Data Line Connections

An RS232C bi-directional serial data link from a computer may be connected via the 25 way D-socket labelled RS232 on the rear panel. The unit is configured as a Data Communication Equipment (DCE) and may be connected directly to a computer or a data terminal, configured as a Data Termination Equipment (DTE). If the power supply is to be connected to a computer which is itself configured as a DCE, pins 2 and 3 should be swapped in the interconnecting cable.

Pin connections at the RS232 socket are:

2	TxD	Received Data (From Computer)
3	RxD	Transmitted Data (To Computer)
4	RTS	Linked to 5
5	CTS	Linked to 4
6	DSR	+5V when unit is powered up
7	GND	Signal Ground
8	DCD	+5V when unit is powered up

All other pins are open circuit.

Voltage levels for the transmitted and received data are:

Tx Data High	> +5.5V
Tx Data Low	< -5.5V
Rx Data High Threshold	< +2.6V
Rx Data Low Threshold	> +1.4V
Max Rx Input Voltage	+/-30V

Data protocols are:

Baud Rate	9600
Tx Start Bits	1
Tx Data Bits	8
Tx Stop Bits	2
Rx Start Bits	1
Rx Data Bits	8
Rx Stop Bits	1 or more

For normal ASCII exchanges the 8th data bit is treated as a parity bit. It is always set to "0" on transmitted data. It is ignored on received data.

3.6 *IEEE-488 Interface*

For use on the General Purpose Interface Bus. (GPIB, HPIB or IEEE-488) an IEEE-488 to RS232 conversion unit is available. This locates externally and is linked by a cable to the RS232 socket on the rear panel. The conversion unit requires a separate mains power supply. Separate operating instructions are supplied with this unit.

3.7 *Auxiliary Port Connections*

The auxiliary port is a 15 way D-type connector on the rear panel, it is marked "PARALLEL I/O" (which corresponds to SKT1202 on diagram CBD1202 sheet 2/2). It serves two separate functions.

1) It provides an input command to de-energise a superconducting magnet.

2) It provides an output confirming the output current is within a defined range.

The outputs are open-collector transistors (specification as for ULN2803A) and can sink up to 500mA from a supply of up to 25 volts maximum. When driving an inductive load, it is recommended that a diode is connected across the load to absorb the stored energy.

For low power loads, current may be drawn directly from pin 15, which is connected via a diode and fuse, to the internal unregulated 11 volt line. A maximum total current of 500mA may be drawn from this source.

The input lines on the auxiliary socket are suitable for either TTL level inputs or contact closures to +5V. The input device is a 74HC244 and 100 kohm pull-down resistors to 0V are fitted.

Pin connections at this socket are:

1	Output Bit 0	(spare)
9	Output Bit 1	(spare)
2	Output Bit 2	(spare)
10	Output Bit 3	(spare)
3	Output Bit 4	(spare)
11	Output Bit 5	(spare)
4	Output Bit 6	(spare)
12	Output Bit 7	(Safe Current Interlock)
5	Input K4	(spare)
13	Input K5	(spare)
6	Input K6	(spare)
14	Input K7	(Auto-Run-Down)
7	+5V	
15	Driver Protection / +11V unregulated.	
8	0V	

Safe Current Interlock

The safe current interlock is provided for users who require hardware confirmation that the measured power supply current is within a safe current range. The upper and lower current limits are set by the user, see section 8.6.

The "safe" condition is signalled by pin 12. If the current is "safe", the associated output transistor will sink current, otherwise it will be high-impedance. A recommended interlock circuit would consist of 10mA or so being drawn from pin 7 (at +5V) via an opto-coupler.

The safe-current status can also be read using the serial data "X" command. However it is not indicated on the front panel.

Auto-Run-Down

Auto-run-down will automatically de-energise a magnet system. The function is described in section 7.

To activate auto-run-down, pin 14 should be taken to logic 1 (+5V) relative to pin 8 (0V). The recommended means by which to achieve this is by galvanically isolated contact-closure (i.e. a relay) between pins 7 and 14.

For example, a low helium level will trigger an auto-run-down if connections are made to a pair of terminals marked "COM" and "LOW" on an Oxford Instruments HLM2 helium level meter.

3.8 Measured Current

On the rear panel of the power supply is an isolated BNC connector, marked "MEASURED CURRENT". This provides a 0 to -10 volt analogue signal from the shunt amplifier, the outer screen is connected to the internal 0 volts, not to protective ground.

0 volts represents a magnet current of 0 amps.
-10 volts represents a magnet current of 180 amps.

4 LOCAL OPERATION

4.1 Front Panel Controls

The majority of the operating controls are located on the front panel and are grouped together in logically related boxes.

POWER

The main ON/OFF switch. When off, the red STANDBY lamp is lit, when the instrument is switched on, this lamp extinguishes and the green POWER ON lamp illuminates.

ADJUST

The red RAISE and LOWER buttons provide the main means of adjusting any parameter. They have no effect on their own but are always used in conjunction with one of the other buttons. Whenever a parameter is being adjusted, its current value is shown on the main display. Setting a value involves pressing RAISE or LOWER until the required value is shown. Operation of the RAISE and LOWER controls has been designed to allow large changes to be made relatively quickly whilst at the same time enabling any value to be set exactly. Pressing RAISE or LOWER briefly will cause the value to change by one unit. If the button is held in, the last figure will start to change at about 5 units per second. After 2 seconds, an approximately 10-fold increase in rate will occur, followed after another 2 seconds by a further rate increase and so on. Altogether there are 4 different rates. Whenever RAISE or LOWER is released, the next lower speed will be selected. This allows the user to "home-in" on the required value most ergonomically.

CONTROL

Control of the instrument may either be LOCAL from the front panel, or REMOTE via the RS232 interface. The LOC/REM button may be used to switch between LOCAL and REMOTE. A third mode, Auto-Run-Down, is selectable via a socket on the rear panel.

When LOCK is lit, the instrument is locked into either local or remote control and the LOC/REM button has no effect. At power up, it is locked in LOCAL, since at that time the instrument has no way of knowing if there is a computer connected to the RS232 interface.

When the instrument is in REMOTE but not LOCKed, many of the front panel controls are inoperative. Those controls which only affect the display, will still work but those which could change the operation of the instrument are disabled.

When in REMOTE and LOCKed, the front panel is completely inoperative.

Auto-Run-Down locks out both LOCAL and REMOTE control. This state is indicated when the "control" lights are flashing, see section 7.

SWITCH HEATER

This controls the heater supply for a superconducting switch on the magnet (if fitted). The HEATER ON lamp indicates that the heater is on and the superconducting switch is open, allowing the magnet to be energised. When the lamp is off, the heater is un-powered and the superconducting switch is closed, putting the magnet into persistent mode.

The associated button allows the heater to be switched on and off. In order to prevent inadvertent damage to the magnet system, the switch heater can only be turned on if the power supply current matches the magnet current in both magnitude and polarity (+/- zero amps are considered equal). The magnet current is recorded as the current in the power supply when the magnet was last put persistent. The record is updated whenever the switch heater is de-energised or if voltage limiting occurs.

If there is a mismatch of the currents, then the current that the power supply believes to be in the magnet (magnet current) is displayed for as long as the switch heater button is depressed. This safety feature can be overridden by holding down the switch heater button for a period of four seconds after which the switch heater is energised and the display reverts to displaying demanded current.

NB It is usually necessary to wait several seconds after operating the button before the superconducting switch changes state.

The current flowing through the switch heater may be adjusted to match an individual switch by means of the control on the rear panel. Where the power supply has been supplied with a magnet, the heater current will be set during final system test.

POLARITY

The power supply will automatically switch the polarity of a magnet between forward and reverse fields. When the power supply performs a polarity change it first ensures that the output current is at zero, then a clamp (or short circuit) is placed across the output, the clamp is then released with the magnet polarity in the opposite direction to the original.

The FORWARD and REVERSE lamps indicate that the power supply is providing magnet current in the forward or reverse sense. OUTPUT CLAMPED indicates that the power supply is placing a short circuit across the magnet. The power supply must always be in one of the three mutually exclusive states; Forward, Reverse or Output Clamped.

The CHANGE POLARITY button has no effect when pressed on its own. However, while SET POINT is depressed, pressing CHANGE POLARITY causes the polarity of the Set Point current, or field, to toggle. The sign of SET POINT corresponds to the polarity of the target current, a positive or negative SET POINT indicates a FORWARD or REVERSE target current.

The CHANGE POLARITY button can also be used to enter TEST mode, see section 8.1

SWEEP CONTROL

HOLD, ZERO and SET POINT buttons may be used to control the power supply output current, these states are indicated by three lamps. If none of these lamps are lit then the power supply must be in a fourth state, "Clamped".

Clamped

The magnet is clamped or short circuited. This state is only reached from the front panel when the power supply is turned on (or off). This is a "safe" state for a superconducting magnet, for example in an emergency it can be used to run a magnet to zero, although as the stored energy of the magnet is dissipated only by the lead resistance this is a rather slow method for de-energising a magnet.

When the power supply is clamped, HOLD is the only state that can be entered.

HOLD

Unclamping a magnet. The power supply will connect to the magnet in the SET POINT direction. However, if the power supply senses a significant current flowing through the magnet leads, this will override and the clamp will open in the same direction as the measured current.

Stopping a sweep. The power supply output current and polarity will remain at the same values indefinitely.

A number of secondary functions are performed by HOLD, these are:-

a) The "Hot" and "Quenched" states are cleared.

b) With a finger on HOLD, pressing (display) SET POINT will cause the last recorded "Trip Current" or "Trip Field" to be displayed, see section 4.2.

c) With a finger on HOLD, pressing RAISE or LOWER will cause "FASt" or "trAin" to be displayed and toggles between two maximum magnet sweep rate profiles. Fast is the power up state and is restored whenever

the power supply is clamped. Train is intended for magnets that may need training after they have been warmed and for that period must then be run at lower sweep rates. The limiting rates are variables, see section 8.6.

ZERO

Causes a sweep towards zero current or field.

SET POINT

Causes the power supply to sweep towards the set point current or field.

The rate at which a sweep will proceed depends on what the power supply is "looking at". If there is no superconducting switch fitted or there is but the switch heater is energised, then the power supply assumes it is passing current through a magnet and output changes are made in "sweep mode". If, however, there is a superconducting switch fitted and it is not being heated, then the power supply assumes it is passing current through a superconducting switch and output changes are made in "immediate mode".

If the perceived load is a switch, then the (immediate mode) sweep rate is at a fast rate which is usually 300 amps/minute but can be less, see section 8.6. If the load is magnetic then the (sweep mode) sweep rate will be at that defined by the SET RATE button in the "DISPLAY" box unless the rate exceeds and is limited by the maximum magnet sweep rate, see RATE LIMITING.

N.B. if voltage limiting should occur at any point, the power supply will "catch" the magnet and drop the power supply into the HOLD state, see section 4.2.

QUENCH

Indicates that the power supply has detected a sudden decrease in the output current. This is a very unusual event and should it occur it is quite likely to be caused by a magnet quench. For some magnets there is a possibility that a small winding may quench but not the bulk of the magnet, the small part absorbs most of the magnet's stored energy and causes damage to the wire. Secondly, damage may occur to a persistent magnet switch heater if power is continuously dissipated therein while there is no liquid helium left to cool it.

For these reasons a "QUENCH" will cause the power supply to take control. The power supply will sweep quickly to zero amps within +2V, -20V voltage limits. About a minute after the magnet has settled at zero current, the power supply will clamp the output and turn off the switch heater. When a quench is detected, the power supply current will be

recorded as the "Trip Current", displayed with a finger on HOLD and pressing (display) SET POINT.

To clear the QUENCH state and regain control at any time, the operator should press the HOLD button.

RATE LIMITING
This lamp indicates that the power supply output current is no longer being swept at the rate defined by SET RATE but is under the control of a preset software limit, the maximum magnet sweep rate. As the power supply only tries to sweep at the SET RATE when looking at a magnet, this warning lamp should not light when driving current into a superconducting switch.

Software sweep rate limits are sometimes installed at the factory to protect a magnet from damage caused by sweeping it too fast. To change a limit see section 8.6.

DISPLAY

The main display normally indicates the delivered current in amps or the equivalent field in tesla. Provided the supply is not voltage limiting this will give an accurate indication of the actual power supply output.

When the supply is in voltage limit, see section 4.2, the display will flash to warn the operator that the number displayed is the target current or field rather than the actual output. Under these conditions the analogue meter on the front panel indicates the actual current.

"Hot" MESSAGE
It is possible that the display may read "Hot" instead of a number, this indicates either that the transistor bank has overheated or in the case of a High Stability PS180-20 that the water cooled shunt has overheated. The "Hot" state will cause the power supply to clamp.

The power supply should be left to cool with the power still on (thus powering the fans) or the water turned on! Pressing the HOLD button will restore normal operation but only if the overheated part has cooled down.

Buttons associated with the display allow this to be switched to display other parameters. These are displayed whilst the appropriate button is pressed. As soon as it is released the normal display returns. Whilst SET POINT or SET RATE are pressed, RAISE and LOWER may be used to adjust the parameter concerned, provided the unit is in LOCAL control.

VOLTS/AMPS/TESLA

The units of the displayed parameter are indicated by these three lamps. In the case of SET RATE, the units are amps/minute or tesla/minute.

CURRENT/FIELD

Causes the display to toggle between displaying the various parameters in amps or an equivalent number of tesla. The relationship between current and field is a linear one, the conversion ratio depends on the magnet and will have been set at the factory. To change the ratio see section 8.6.

OUTPUT VOLTAGE

A positive voltage indicates a resistive load or a magnet being charged, a negative voltage can appear when a magnet is discharged. The sign of the displayed voltage is independent of forward and reverse magnet polarities.

SET POINT

Displays the target point for a sweep either as current or the equivalent field. Using RAISE and LOWER it may be adjusted between 0 and 180.01 amps, or 0 and the maximum magnet current if a current limit has been installed, see section 8.6.

Whilst holding the SET POINT button, the target polarity can be toggled by the CHANGE POLARITY button. The sign of SET POINT corresponds to the polarity of the target current, a positive or negative SET POINT indicates a FORWARD or REVERSE target current.

With a finger on HOLD, pressing (display) SET POINT will cause the last recorded "Trip Current" or "Trip Field" to be displayed, see section 4.2.

SET RATE

Displays the sweep rate in amps per minute or the equivalent tesla per minute. Values between 0.01 and 300.01 amps per minute may be set. Whilst sweeping, the SET RATE may exceed the maximum magnet sweep rate, in which case the sweep rate will be limited and RATE LIMITING will be illuminated. At very high sweep rates the power supply output voltage may be insufficient to enable a magnet to follow the sweep and the power supply will voltage limit, see section 4.2.

N.B. The SET RATE is only observed when in sweep mode, eg the power supply believes it is driving a magnet. If a superconducting switch is fitted and it is persistent, the sweep is in immediate mode and is at the

rate limit e.g. 300 amps/minute, or less if the limit has been reduced (see section 8.6).

4.2 *Voltage Limiting*

Voltage limiting can result from several causes e.g. a magnet being swept too fast, a magnet quench or a superconducting switch breaking open.

Two voltage limits exist, fast hardware voltage limits (usually set to +/- 20 volts), and slow software voltage limits. In normal use, the power supply output voltage will stay within both sets of limits. However, if a limit is exceeded the power supply will go into "catch" mode and stabilise the magnet system by matching the power supply current to the magnet current. Whilst voltage limiting the display will flash as there may be a discrepancy between the actual power supply output current and the displayed current.

When the power supply first reaches a voltage limit, the power supply output is recorded as the trip current, displayed by pressing HOLD and display SET POINT (see above). When a magnet has been "caught" the power supply is left in its HOLD state and the (persistent) magnet current and polarity are updated (thus an accurate record of magnet current is kept even if a superconducting switch should heal at a current different from that at which the operator last turned off the switch heater).

Software voltage limits are not commonly used, they are intended to protect magnets at the end of long or very resistive leads, otherwise they are inhibited. The limits are usually set to be just below the voltage of the magnet protection network. Exceeding this limit means that current must be in the protection network, if the condition persists for more than a preset period (e.g. 2 seconds), the magnet will be "caught". As the power supply continuously monitors the voltage drop due to the magnet lead resistance there is no need to make allowance for this in setting software limits, see section 8.6.

4.3 *Metering*

Analogue meters are mounted on the front panel and will indicate the actual output Current and Voltage of the power supply at all times, even if mains power is lost. They thus provide an important safety feature.

Connections to the magnet should never be broken unless both meters are at zero.

The Output Current scale is marked FORWARD and REVERSE, thus indicating current polarity as well as magnitude . A more accurate digital indication of magnet current may be obtained from digital display on the control unit. However if the power supply should be voltage limiting, the digital display will no longer represent the actual current. Under these circumstances the display will flash, to warn the operator.

The Output Voltage meter is configured such that its polarity matches that of the magnet. Thus the scale is marked CHARGE and DISCHARGE referring to the magnet (rather than referring to the power supply output terminals with names such as PLUS and MINUS).

4.4 *Setting Switch Heater Current*

When the power supply has been supplied with a magnet, the switch heater current will have been set to an optimum value during final system testing. If this needs adjusting for another magnet, the control on the rear panel marked "SET SWITCH HEATER CURRENT" should be used to vary the heater current. The current may be observed by connecting a milliammeter in series with one of the switch heater leads. The current is normally set to the minimum value at which the switch will open reliably after 10-15 seconds.

4.5 *First Time Operation*

For a first-time test, it is suggested that the power supply be operated into a short circuit, by linking the output terminals together with a shorting bar. Once the operation of the power supply is familiar, the short may be removed and the supply connected to a magnet.

Switch on the miniature circuit breaker mounted on the rear panel of the power supply and marked "ISOLATION". This switch should now be left in the on position, the front panel ON/OFF switch is for every-day use.

The red STANDBY lamp should be lit, indicating that mains power is connected. Switch on the instrument by means of the ON/OFF switch on the front panel, the STANDBY lamp will extinguish and the green POWER ON lamp illuminates.

After about one second a message such as "PS2.82" will appear on the display. This shows the firmware version and indicates that the power supply has completed its self test and initialisation.

The unit will always power up at zero current, with the output clamped and under LOCAL control.

Decide if the power supply output should be expressed as a current or an equivalent field and if necessary change the display using the CURRENT/FIELD button.

Use the SET POINT and SET RATE buttons to check that these values are as required. (Both parameters are retained in non- volatile memory when power is off). Modify the values if required, by pressing RAISE, LOWER and CHANGE POLARITY whilst holding the appropriate SET button pressed.

If sweeping a switched magnet to field, then turn on the heater by pressing the SWITCH HEATER button, wait 15 seconds for the switch to open.

Press the HOLD button, causing the clamp to release and connecting the magnet in the SET POINT direction.

The power supply output may now be controlled by the HOLD, ZERO and SET POINT buttons.

The display on the control unit will indicate the current being delivered by the power supply or the equivalent field, unless a voltage limit is reached, in which case it will flash, whilst indicating the target output.

5 REMOTE OPERATION

5.1 Introduction

The power supply may be remotely operated by means of its RS232 interface. This allows a computer to interrogate the supply and if required, to take control of it.

When in control, the computer has the option of locking out all the front panel controls, or of allowing the front panel LOC/REM control to remain active, so that an operator may restore LOCAL operation if required.

5.2 Communication Protocols

All dialogue with the power supply is in 9600 baud serial form.

Data sent by the power supply is in the form of 1 start bit, 8 data bits and 2 stop bits.

Data sent by the power supply during normal operation has the 8th (parity) bit always set to zero. When receiving normal data, the power supply ignores the parity bit. (In the "Y" and "Z" diagnostic commands, all 8 bits are used for data).

All commands consist of a string of printing ASCII characters, terminated by a Carriage Return character. A Line Feed character may optionally be sent after the Carriage Return but is ignored by the power supply.

Unless the command starts with a "$" (dollar) character, all commands will evoke a response from the power supply. The response will consist of a string of one or more printing ASCII characters and will be terminated by a Carriage Return Character. This may optionally be followed by a Line Feed character.

The response will normally be sent immediately following the command. If a front panel button is pressed when the command is received, the response may be delayed until the button is released.

If the first character of a command is a "$", the command will be obeyed but no response will be sent. (See section 5.5).

None of the RS232 Modem control lines are required by the power supply, though signals are returned on some of the more common ones for maximum compatibility with other equipment.

The power supply will accept a command string at all times. If a computer is unable to accept data from the power supply at the full rate of the 9600 baud interface, the "W" command may be used to instruct the power supply to send more slowly. (See section 6.1).

5.3 *Commands and Responses*

Commands to the power supply all consist of a single upper-case letter, optionally followed by a numeric parameter, the whole being terminated by a Carriage Return. The response sent by the power supply varies depending on the command. Usually it consists of the command letter received, followed by the value of any data requested. Where a command instructs the power supply to carry out an action rather than to send data, the command letter alone will be returned.

If a command is not recognised, has an illegal parameter or cannot be obeyed for any reason, an error response will be sent. This consists of a "?" (question mark), followed by all or part of the command string in question. To simplify error handling in the computer, the "?" will always be the first character returned.

The most common reason for a command error is attempting to execute a control command whilst the power supply is in LOCAL control. If in doubt, the "X" command may be used to determine the current status.

5.4 *Numeric Parameters*

All numeric parameters are treated as signed integers and are sent as a string of decimal digits. The range of acceptable numbers is -32768 to +32767. Alternatively, positive numbers in the range 0 to 65535 will be accepted, if preceded by a "#" (hash) symbol. Numbers outside this range will give an error.

For positive numbers, the "+" sign is optional, as are leading zeros. Any spaces, full stops and commas embedded within the number are ignored.

Thus to set a sweep rate of 12.00 amps/minute;

S1200	is the preferred command form,
S12.00	is an alternative form which would be accepted and correctly obeyed,
S12	will result in an erroneous sweep rate of 0.12 amps/minute.
S12.0	will result in an erroneous sweep rate of 1.2 amps/minute.

Hence unless you can be confident that your computer will always send a specific number of decimal places, it is preferable to convert all data to integers.

For example in BASIC, the instruction:

```
LET N = INT(100*RATE)
```

might be used.

The same convention is adopted by the power supply in returning numbers to the computer. Thus 23.09 would be returned as +02309.

The convention of sending all numbers as integers has been adopted to maintain compatibility with the maximum number of computers. It avoids any problems caused by the various formats used by different machines, to represent floating point numbers.

5.5 Use with OXFORD ISOBUS

The OXFORD ISOBUS allows a number of instruments to be driven in parallel from a single RS232 port on a computer, using a special cable assembly.

To allow separate instruments to be distinguished, each is allocated a unique address in the range 1 to 9. Depending on the instrument this may be set up in hardware, or held in non-volatile memory. In the case of this power supply the latter option is used.

When operating on ISOBUS an instrument must be able to recognise and respond to commands addressed to it, whilst ignoring commands addressed to other instruments. This is achieved by starting all commands with a special ISOBUS control character.

When more than one powered-up instrument is connected on ISOBUS, no command should be issued which does not have an ISOBUS control character as its first character. Issuing such a command would result in an unintelligible response, as all instruments would reply together. (N.B. This will only result in lost data. No hardware damage will be caused).

Following the control character and its parameter (where required), the rest of the command follows the form described above. The response of the instrument depends on the initial control character in the following manner:

@n (At) addresses the command to instrument number n, where n is a digit in the range 1 to 9. This instrument obeys the command and returns its usual response. All other instruments ignore the command and send no reply.

$ (Dollar) instructs all instruments to send no reply. This is normally used to precede a command being sent to all instruments simultaneously, and prevents a conflict as they all echo the command together.

It may also be used in non-ISOBUS applications if the computer does not wish to receive a response.

It should be used with caution however, since all responses are suppressed, including the "?" error response. Thus the computer has no

way of knowing if a command has been received or even if the instrument is connected.

If a command is to be addressed to a specific instrument, but no reply is required, it is permissible to use "$" and "@n" together. The "$" should always come first.

& (Ampersand) instructs an instrument to ignore any following ISOBUS control characters. It is included in the ISOBUS protocol to allow instruments whose command repertoire includes "@", "$", "&" or "!" to be used on ISOBUS. The power supply does not require the use of this command.

!n (Exclamation) instructs the instrument that from now on, its address is to be n. This command is included here since it is relevant to ISOBUS operation. However for obvious reasons, it should not be sent when more than one instrument is powered up and connected to ISOBUS. (It would result in all instruments having the same address!). The command is intended for initial setting up of instruments, one at a time. To avoid inadvertently changing addresses, the "!" command will only be obeyed following a "U" command with a non-zero password. (See section 6).

6 COMMAND SYNTAX

For a more detailed explanation of the power supply states, the user should refer to section 4, Local Operation.

Commands fall into 4 categories:

Monitor Commands
which are always recognised.

Control Commands
which are only recognised when in REMOTE control.

Field Step Control Commands
are commands which allow for direct control in discrete field steps. Only recognised when in REMOTE control.

System Commands
which are only recognised after receipt of the correct "UNLOCK KEY".

In the lists which follow "n" & "m" represent decimal digits 0-9.

6.1 *Monitor Commands*

Cn *SET CONTROL (LOCAL/REMOTE)*

The control command sets the power supply into LOCAL or REMOTE and determines whether the LOC/REM button is LOCKED or active. At power up the power supply defaults to the C0 state. Allowed values are:

C0	LOCAL & LOCKED (Default State)
C1	REMOTE & LOCKED
C2	LOCAL & UNLOCKED
C3	REMOTE & UNLOCKED

Qn *DEFINE COMMUNICATIONS PROTOCOL*

Defines the communication protocol.
Currently only 8 values of n are significant:

Q0	"Normal" (Default Value)
Q2	Sends <LF> after each <CR>
Q16	Reduced Protocol (mimics PS126)
Q18	Reduced Protocol & <LF> after <CR>
Q48	Aerosonics Protocol (1.38 firmware or later)
Q50	(Aerosonics Protocol & <LF> after <CR>)
Q80	Aerosonics Protocol (1.37 firmware or earlier)
Q82	(Aerosonics Protocol & <LF> after <CR>)

The <LF> option is for use with computers that require an <LF> as an input message terminator. Reduced protocol simplifies the "X" status message (see below), and allows fewer options in the mode command. It is provided to allow some compatibility with the earlier PS126 power supply. The Aerosonics option, Q48, should be used for all VSM systems driven by 1.38 firmware or later. For VSM systems using 1.37 firmware or earlier, select Q80.

N.b. the Q command is volatile, when the power supply is switched off and on, the communication protocol reverts to a default value eg Q0. However, the power supply can be made to default to Reduced or Aerosonics Protocol by changing the "Magnet System Configuration", Test 06 in section 8.4.

Rnn *READ PARAMETER nn*

The READ command allows the computer to interrogate any of a number of variables. The returned value is always an integer as defined in section 5.4. Allowed values for n are listed below. Variables marked with a "*" are intended as service diagnostics and are unlikely to be of use to the user.

R 0	DEMAND CURRENT TO PSU (OUTPUT CURRENT)	
R 1	MEASURED POWER SUPPLY VOLTAGE	
R 2	MEASURED MAGNET CURRENT	
R 3	UNUSED	
R 4	DEMAND CURRENT (duplicate of R0)	
R 5	SET POINT (TARGET),	CURRENT A
R 6	SWEEP RATE,	CURRENT A/MIN
R 7	DEMAND FIELD (OUTPUT FIELD)	
R 8	SET POINT (TARGET),	FIELD T
R 9	SWEEP RATE,	FIELD T/MIN
R 10 *	LEAD RESISTANCE, milli Ohm	
R 11 *	CHANNEL 1 FREQ/4	
R 12 *	CHANNEL 2 FREQ/4	
R 13 *	CHANNEL 3 FREQ/4	
R 14 *	DACZ (PSU zero correction as a hexadecimal number)	
R 15	SOFTWARE VOLTAGE LIMIT	
R 16	PERSISTENT MAGNET CURRENT	
R 17	TRIP CURRENT	
R 18	PERSISTENT MAGNET FIELD	
R 19	TRIP FIELD	
R 20 *	IDAC (demand current as a hexadecimal number)	
R 21	SAFE CURRENT LIMIT, MOST NEGATIVE	
R 22	SAFE CURRENT LIMIT, MOST POSITIVE	

Unnnnn UNLOCK SYSTEM COMMANDS

The UNLOCK command allows access to the SYSTEM commands. This set of commands is intended for diagnostic and configuration purposes and have the power to erase or modify the contents of the non-volatile memory. The U command must be followed by the correct KEY parameter before these "dangerous" commands may be used.

These commands should only be used after consultation with Oxford Instruments who will advise the correct KEY. (N.B. The Z command can do no harm and does not require a key).

A lower level of key protection is provided for the "L" and "!" commands, to avoid accidental errors. Allowed values of U are:

U0	LOCKED (Power-up Default)
U1	"L" and "!" COMMAND UNLOCKED
Unnnnn	"Y" COMMAND UNLOCKED

V *READ VERSION*

The VERSION command requires no parameters. It returns a message indicating the instrument type and software version number.

For example: "PS Version 2.82 (c) OXFORD 1993"

Wnnnn *SET WAIT INTERVAL*

The WAIT command sets a delay interval before each character is sent from the power supply via the serial interface. This allows the power supply to communicate with a slow computer with no input buffering. The parameter nnnn specifies the delay in milliseconds. It defaults to zero at power-up.

N.B. the W command does not reduce the rate at which the power supply can accept data from computer.

X *EXAMINE STATUS*

The EXAMINE command allows the computer to read the current power supply STATUS. It requires no parameters and will return a message string of the form:

XmnAnCnHnMmnPmn

n.b. the length of the returned string is fixed (at 15 characters).
The digits "m" & "n" have the following meaning:

Xmn	SYSTEM STATUS	
	m=0	NORMAL
	m=1	QUENCHED
	m=2	OVER HEATED
	m=4	WARMING UP
	n=0	NORMAL
	n=1	ON POSITIVE VOLTAGE LIMIT
	n=2	ON NEGATIVE VOLTAGE LIMIT
	n=4	OUTSIDE NEGATIVE CURRENT LIMIT
	n=8	OUTSIDE POSITIVE CURRENT LIMIT
An	ACTIVITY (n as for A command)	
	n=0	HOLD
	n=1	TO SET POINT
	n=2	TO ZERO
	n=4	CLAMPED

Cn	LOC/REM STATUS (n as for C command)			
	n=0	LOCAL & LOCKED		
	n=1	REMOTE & LOCKED		
	n=2	LOCAL & UNLOCKED		
	n=3	REMOTE & UNLOCKED		
	n=4	AUTO-RUN-DOWN		
	n=5	AUTO-RUN-DOWN		
	n=6	AUTO-RUN-DOWN		
	n=7	AUTO-RUN-DOWN		
Hn	SWITCH HEATER (n as for H command)			
	n=0	OFF (switch closed) MAGNET AT ZERO		
	n=1	ON (switch open)		
	n=2	OFF (switch closed) MAGNET AT FIELD		
	n=8	NO SWITCH FITTED		
Mmn	MODE	(m as for M command)		
		Display	Mode	Magnet Sweep
	m=0	AMPS	IMMEDIATE	FAST
	m=1	TESLA	IMMEDIATE	FAST
	m=2	AMPS	SWEEP	FAST
	m=3	TESLA	SWEEP	FAST
	m=4	AMPS	IMMEDIATE	TRAIN
	m=5	TESLA	IMMEDIATE	TRAIN
	m=6	AMPS	SWEEP	TRAIN
	m=7	TESLA	SWEEP	TRAIN
	n=0	AT REST		(output constant)
	n=1	SWEEPING		(output changing)
	n=2	RATE LIMITING		(output changing)
	n=3	SWEEPING & RATE LIMITING		(output changing)

The active states "SWEEPING" and "RATE LIMITING" indicate the mode in which the output current is changing.

A changing output in IMMEDIATE mode (e.g. magnet persistent) will be flagged by RATE LIMITING only. In SWEEP mode (e.g. changing the magnet current) only SWEEPING should be flagged, but if the attempted sweep rate exceeds the sweep rate limit, RATE LIMITING will also be indicated.

Pmn	POLARITY	Desired	Magnet	Commanded
	m=0	FORWARD	FORWARD	FORWARD
	m=1	FORWARD	FORWARD	REVERSE
	m=2	FORWARD	REVERSE	FORWARD
	m=3	FORWARD	REVERSE	REVERSE
	m=4	REVERSE	FORWARD	FORWARD
	m=5	REVERSE	FORWARD	REVERSE
	m=6	REVERSE	REVERSE	FORWARD
	m=7	REVERSE	REVERSE	REVERSE
	n=0	OUTPUT CLAMPED	(Transition)	
	n=1	FORWARD	(Verification)	
	n=2	REVERSE	(Verification)	
	n=4	OUTPUT CLAMPED	(Requested)	

Desired Polarity	is the final or target polarity, it is the polarity of the SET POINT current.
Magnet Polarity	is the polarity of the power supply last time the magnet was left persistent.
Commanded Polarity	is the present polarity of the power supply unless, that is, the output is clamped for any reason.
Forward & Reverse Verification	indicates the actual state of the change-over switch.
Output Clamped Transition/Request	both signals indicate that the power supply is in the clamped state.

X EXAMINE STATUS, REDUCED PROTOCOLS

For Reduced Protocol or Aerosonics Protocol (seldom used), as selected by the Q16 or Q48 commands respectively, EXAMINE will not transmit the "m" digit for the X, M & P entries. The complete response becomes:

XnAnCnHnMnPn

where "n" has the same meaning as for the normal EXAMINE response, except:

for Reduced Protocol;

Mn	MODE		
	n=0	IMMEDIATE MODE	(ignore SWEEP RATE)
	n=1	SWEEP MODE	(follow SWEEP RATE)

and for Aerosonics Protocol;

Mn	MODE	
	n=1	ALWAYS

6.2 *Control Commands*

An *SET ACTIVITY (HOLD/UP/DOWN/CLAMP)*

The ACTIVATE command corresponds to the use of the HOLD, SET POINT and ZERO buttons on the front panel, a fourth state, CLAMP, can also be selected, corresponding to the state in which the PS180-20 powers up. Allowed values for n are:

A0	HOLD
A1	TO SET POINT
A2	TO ZERO
A4	CLAMP (Clamp the power supply output)

When the power supply is in its clamped state, A1 and A2 will not be recognised.

Fnn *SET FRONT PANEL TO PARAMETER nn*

The FRONT PANEL DISPLAY command sets the display to show one of the internal parameters rather than the normal demanded current or field. "nn" may take the same values as for the "R" command above, with the same significance. Normal display operation may be restored by sending an F0 or F7 command for current or field display respectively, by an M command which automatically sets the correct display for the selected mode or by pressing the CURRENT/FIELD button twice. The command is intended chiefly for use during test and fault diagnosis.

Hn *SET SWITCH HEATER (OFF/ON)*

The HEATER command activates the switch heater, controlling the superconducting switch, if fitted. Allowed values for n are:

H0	HEATER OFF	(CLOSE SWITCH)
H1	HEATER ON IF PSU=MAGNET	(OPEN SWITCH)
H2	HEATER ON, NO CHECKS	(OPEN SWITCH)

The H1 command will only open the switch if the recorded magnet current and polarity are equal to the present power supply output current and polarity (+/- zero amps are considered equal). The H2 command performs no such check, and will open the switch regardless of any apparent conflict.

N.B. a) After issuing a command it is necessary to wait several seconds for the switch to respond before assuming that it has changed state.

b) Changing the state of the switch heater will automatically set sweep or immediate mode. Immediate mode is selected only if a superconducting switch is fitted and is closed. Otherwise the control of the power supply is always in sweep mode. Note that in immediate

mode, changes occur at a limiting rate eg. 300 amp/minute, not as an instantaneous step. In sweep mode, changes occur at a rate specified by the S or T command, unless this would exceed the rate limit.

Innnnn *SET TARGET CURRENT*

The I command sets the SET POINT (target) current to which the power supply will sweep. The parameter nnnnn is the required current in units of 0.01 Amp sent as an integer in accordance with section 5.4 and should be positive. Current polarity is defined by a previous or subsequent P command.

Jnnnnn *SET TARGET FIELD*

The J command sets the SET POINT (target) field to which the power supply will sweep. The parameter nnnnn is the required field sent as an integer in accordance with section 5.4, eg in units of 0.001 Tesla, the integer should be positive. Field polarity is defined by a previous or subsequent P command.

Mn *SET MODE*

The MODE command selects CURRENT or FIELD mode for the display, selects SWEEP or IMMEDIATE response to changes in demand and selects FAST or TRAIN maximum sweep rates for the magnet. Usually the user will require only to toggle the display between "Amps" and "Tesla", for which M8 and M9 will suffice.

Mn may take the following values:

	Display	Mode	Magnet Sweep
M0	AMPS	IMMEDIATE	FAST
M1	TESLA	IMMEDIATE	FAST
M2	AMPS	SWEEP	FAST
M3	TESLA	SWEEP	FAST
M4	AMPS	IMMEDIATE	TRAIN
M5	TESLA	IMMEDIATE	TRAIN
M6	AMPS	SWEEP	TRAIN
M7	TESLA	SWEEP	TRAIN
M8	AMPS	Unaffected	Unaffected
M9	TESLA	Unaffected	Unaffected

SWEEP/IMMEDIATE In immediate mode, changes occur at a limiting rate eg. 300 amp/minute, not as an instantaneous step. In sweep mode, changes occur at a rate specified by the S or T command (the sweep rate), unless this would exceed the rate limit. The limiting rates are variables, see section 8.6.

Normally sweep and immediate modes should be left to the adjudication of the power supply. Immediate mode is selected

only if a superconducting switch is fitted and is closed. Otherwise the control of the power supply is always in sweep mode.

FAST/TRAIN — This facility protects the magnet from damage due attempting to sweep too fast. Two maximum magnet sweep rate profiles are allowed. FAST is the power up state and is restored whenever the power supply is clamped. TRAIN is intended for magnets that may need training after they have been warmed and for that period must then be run at lower sweep rates. The limiting rates are variables, see section 8.6.

Mn SET MODE, REDUCED PROTOCOLS

For Reduced Protocol, as selected by the Q16 command, Mn has the same meanings as those described in the Reduced Protocol EXAMINE (X) command.

M0	IMMEDIATE MODE	(ignore SWEEP RATE)
M1	SWEEP MODE	(follow SWEEP RATE)

However, if Aerosonics Protocol has been set, eg by the Q48 command, then SWEEP MODE can not be selected by the M command.

M0	IMMEDIATE MODE	(ignore SWEEP RATE)
M1	IMMEDIATE MODE	(ignore SWEEP RATE)

Pn SET POLARITY (FWD/REV/CHANGE-OVER)

The POLARITY command sets the desired polarity of the output current. If the activity is set to SET POINT and the polarity is to be changed, the power supply will cause a sweep to zero, change the polarity of the magnet and then sweep up to the set point current. Allowed values for P are:

P0	NO ACTION
P1	SET FORWARD
P2	SET REVERSE
P4	SWAP POLARITY

Snnnnn SET SWEEP RATE (AMPS/MINUTE)

The SWEEP RATE command sets the sweep rate (Amps/Minute) determining the rate at which the power supply will sweep the current in SWEEP mode. The parameter nnnnn is the required sweep rate in units of 0.01 Amp/Min. sent as an integer in accordance with section 5.4. The sweep rate selected will only apply when the power supply is operated in SWEEP mode, eg. when the superconducting switch is open. However it is not necessary for the PSU to be in sweep mode when the S command is issued.

Tnnnnn SET SWEEP RATE (TESLA/MINUTE)

The SWEEP RATE command sets the sweep rate (Tesla/Minute) determining the rate at which the power supply will sweep the magnet field. The parameter nnnnn is the required sweep rate sent as an integer in accordance with section 5.4, eg in units of 0.001 Tesla/Min. The sweep rate selected will only apply when the power supply is operated in SWEEP mode, eg. when the superconducting switch is open. However it is not necessary for the PSU to be in sweep mode when the T command is issued.

6.3 *Field Step Control Commands*

For which there are no equivalent front panel commands.

N.b. the output of the power supply is limited to a step size of 2.75mA (180 amp / 2^{16}). Thus the requested number of gauss will be output as the nearest equivalent multiple of 2.75mA

Dn *SET DELTA GAUSS (FOR G, O and B)*

The DELTA command sets the step size to be used by the G, O and B commands. The units of D are gauss or 0.1 millitesla, the maximum value that will be accepted is 25 gauss.

Delta may be redefined at any time but, for obvious reasons, this should only be done with caution if the power supply is delivering current.

Gnnnnn *GOTO FIELD*

The GOTO command is similar to the Jnnnnn command but the units differ. Gnnnnn sets a target field in multiples of DELTA Gauss, that is:

SET POINT = (G)nnnnn * (D)n

The parameter nnnnn should be a positive integer, the field polarity is defined by a previous or subsequent P command.

O *STEP FIELD ON*

The ON command steps the field on by an amount defined by the DELTA command. Attempts to step the field beyond the maximum allowed will result in the value being limited.

B *STEP FIELD BACK*

The BACK command steps the field back by an amount defined by the DELTA command. If this would take the field below zero, the field will be limited at zero.

6.4 *System Commands*

L *LOAD CALIBRATION*

The LOAD command allows access via the serial link to part of the power supply calibration menu described in section 8.3. At present only L14 is enabled and allows the measured power supply voltage and current to be nulled. This should obviously only be performed when the voltage and current are known to be at zero and ideally when a short circuit rather than a magnet is connected.

The L commands are non-standard to the extent that they do not echo an "L" until they are complete.

To avoid unintentional use of the L command, these commands will not be obeyed unless a non-zero value of the "U" key has been supplied.

Y *LOAD ENTIRE RAM CONTENTS*

The Y command allows the entire contents of the RAM memory to be loaded in binary, via the serial interface. It is not intended as a user command and will only be obeyed after a correct "U" password.

Z *DUMP ENTIRE RAM CONTENTS*

The Z command allows the entire contents of the RAM memory to be dumped in binary, via the serial interface. It is not intended as a user command.

! *SET ISOBUS ADDRESS*

See section 5.5

7 AUTO-RUN-DOWN

Auto-run-down will automatically de-energise a magnet system. It does not provide a particularly fast means of doing so. It is primarily intended for use with a helium level meter as a means of protecting a magnet from damage should the helium level in the magnet cryostat drop too far.

The auto-run-down function is invoked via the rear panel connector marked "PARALLEL I/O". See section 3 "Auxiliary Port Connections".

While auto-run-down is active, local and remote control are locked out and the lights in the front panel section marked "CONTROL" will flash. The operator may only regain control when the auto-run-down signal is removed.

The following sequence of actions are performed when auto-run-down is active:-

i) If the magnet is persistent, CLAMP the power supply and turn on the switch heater. Wait 20 seconds for the system to stabilise. Then open the clamp.

ii) If the magnet is not persistent or after i), de-energise the magnet in a low-voltage mode e.g. +/- 2 volt.

iii) When the magnet is de-energised, wait 20 seconds to ensure no further activity, then clamp the output and turn off the switch heater (if fitted).

8 TEST MODE

8.1 Entry to Test Mode

The power supply performs a basic self test of the microprocessor and memory at switch on, before displaying the firmware version message e.g. "PS2.82". A more detailed hardware test mode is accessed by one of two methods, either press the internal RED button, SW1, on the digital circuit board; or, hold in the CHANGE POLARITY button then press LOC/REM, RAISE and LOWER all at the same time. This will result in the message "tESt", which will shortly be followed by the test menu, consisting of a letter "t" and an integer. Test routines which may be of use to the user are described below.

Selecting a given test involves using RAISE and LOWER to display the test number required, then pressing LOC/REM to activate the test. Note that "t 00" is the correct route for exit.

WARNING

A complete memory initialisation may be achieved by pressing the internal RED button whilst holding both RAISE and LOWER pressed. This is a drastic measure which will destroy all the calibration data held in the non-volatile memory and so necessitate a complete re-calibration of the power supply. It should be used only if the memory content is known to be corrupt.

8.2 Test Menu

On entering test mode the message "tESt" is displayed, which will shortly be followed by the test menu, consisting of a letter "t" and an integer; initially, "t 00" will be displayed. RAISE and LOWER may be used to step through the menu options, when the required option is displayed, pressing LOC/REM will select it. The menu is cyclic, so that pressing RAISE when t 07 is displayed, will cycle back to t 00.

The Test Options are:

t 00	RESUME OPERATION (EXIT)
t 01	TEST DISPLAY AND LEDS
t 02	TEST BUTTONS
t 03	DUMP THE CONTENTS OF THE INPUT BUFFER
t 04	SELECT "F" MENU (FRONT PANEL DISPLAY)
t 05	SELECT "P" MENU (POWER SUPPLY CALIBRATION)
t 06	MAGNET SYSTEM CONFIGURATION
t 07	SELECT "S" MENU (SUPERCONDUCTING MAGNET CALIBRATION)

Tests 1,2 and 3 are described below. Test 4,5,6 and 7 are described in sections 8.3 , 8.4 , 8.5 and 8.6 respectively.

Test 01 lights each LED or display segment in turn, then pulls each of the auxiliary output lines low in turn. When the test is complete, the unit returns to the test menu.

Test 02 tests the control buttons. When the test is entered, the display will be blank. If the buttons are pressed, one at a time, each should light a single segment in the upper half of the display. Stuck buttons will give a permanently lit segment. If more than one segment lights for a single button, track shorts are indicated. To leave test 2, POWER must be switched off.

Test 03 dumps the content of the serial input buffer back via the serial output buffer. It may help in diagnosing communication problems.

8.3 Test 04, "F" (Front Panel Display) Menu

allows the front panel display to be set to indicate one of the internal parameters rather than the normal demand current. This produces the same effect as the "Fnn" command described in section 7, without the need to connect a computer.

When test 4 is selected, the display will show "F 00" RAISE and LOWER may be used to select an option in the range 0 to 31 for front panel display. The options are as given in the list for the "Rnn" command in section 5. When the required option has been selected, pressing LOC/REM will implement it. The power supply will return to normal operation but with the selected parameter on display. To restore a normal display "F 00" or "F 07" should be selected, alternatively press the CURRENT/FIELD button.

Options are:-

F 00	DEMAND CURRENT TO PSU (OUTPUT CURRENT)	
F 01	MEASURED POWER SUPPLY VOLTAGE	
F 02	MEASURED MAGNET CURRENT	
F 03	UNUSED	
F 04	DEMAND CURRENT (duplicate of F0)	
F 05	SET POINT (TARGET),	CURRENT A
F 06	SWEEP RATE,	CURRENT A/MIN
F 07	DEMAND FIELD (OUTPUT FIELD)	
F 08	SET POINT (TARGET),	FIELD T
F 09	SWEEP RATE,	FIELD T/MIN
F 10	LEAD RESISTANCE,	milli Ohm
F 11	CHANNEL 1 FREQ/4	
F 12	CHANNEL 2 FREQ/4	
F 13	CHANNEL 3 FREQ/4	
F 14	DACZ (PSU zero correction as a hexadecimal number)	
F 15	SOFTWARE VOLTAGE LIMIT	
F 16	PERSISTENT MAGNET CURRENT	
F 17	TRIP CURRENT	
F 18	PERSISTENT MAGNET FIELD	
F 19	TRIP FIELD	
F 20	IDAC (demand current as a hexadecimal number)	
F 21	SAFE CURRENT LIMIT, MOST NEGATIVE	
F 22	SAFE CURRENT LIMIT, MOST POSITIVE	

8.4 Test 05, "PSU" (Power Supply) Menu

The "Psu" menu provides access to a set of operations designed to be carried out when initially setting up a power supply. The majority will not be needed thereafter unless hardware changes are made.

"Psu" is entered from test 5 in the Test Menu, resulting in "PSU" being briefly displayed followed by "P" and an integer. RAISE and LOWER may be used to step through the menu and LOC/REM used to choose an option.

The table which follows lists the available options.

P 00	RESTART NORMAL OPERATION (Power-up restart)
P 01	NOT USED
P 02	DEFINE POWER SUPPLY CURRENT RANGE
P 03	ADJUST PSU ZERO CORRECTION
P 04	NOT USED
P 05	NOT USED
P 06	NOT USED
P 07	NOT USED
P 08	NOT USED
P 09	NOT USED
P 10	CALIBRATE PSU VOLTAGE AT NEGATIVE VOLTAGE LIMIT
P 11	CALIBRATE PSU VOLTAGE AT POSITIVE VOLTAGE LIMIT
P 12	AUTO-CALIBRATION OF MEASURED CURRENT
P 13	NOT USED
P 14	AUTO-ZERO POWER SUPPLY
P 15	NOT USED

Psu 02 **WARNING, users are advised not to use this option.**

It defines the power supply current range and in the case of the PS180-20 this is always set to 180.00 amps. On entry, RAISE and LOWER may be used to shift the decimal point to the required position. Depress LOC/REM and use RAISE and LOWER to set the number required.

Oxford Instruments advises the user not to change the current range unless a precision high current shunt is available for re-calibration. Note that changing this parameter will also affect all other "Psu" and "Sup" calibrations. Perhaps what is required is Sup 2 ?

Psu 03 allows the power supply zero correction to be manually adjusted. On entry, the present value is displayed as a hexadecimal number, depressing LOC/REM allows this value to be adjusted over a small range. The default setting is 0008H.

For the duration of this test, the output of the power supply is unclamped in the forward direction, thus the offset current can be measured between the magnet terminals. An easy way of doing this is to place a 1 kohm resistor across the output, the "OUTPUT VOLTAGE" meter will now display the offset current to the scale of 1 volt/mA.

Psu 10 and Psu 11 calibrate the power supply voltage monitor. Psu 10 calibrates the measured voltage at the negative (hardware) voltage limit, normally about -20 volts. Psu 11 calibrates the measured voltage at the positive (hardware) voltage limit, normally about +20 volts.

These tests require existing connections to the "magnet" and "switch heater" terminals to be removed. A link should be connected between the positive magnet terminal and the positive switch heater terminal. A voltage meter set to read at least +/-20 volts should be connected from the negative to the positive magnet terminals.

On entry to Psu 10 or Psu 11, the power supply will display "PAUSE" as the output voltage sweeps to the (hardware) voltage limit. The display will then change to show the measured output voltage. To alter the calibration, depress LOC/REM and use RAISE and LOWER to set the display to the voltage measured on the external voltage meter. Releasing LOC/REM causes the output voltage to clamp and drop to about 1/10th of its normal value. Pressing the LOC/REM button once more to return to the "Psu" menu.

Exit from Psu 10 and Psu 11 must be via the correct route else corruption of the zero setting of the power supply will result. Pressing LOC/REM at any time will abort the test and return to the Psu menu.

If large adjustments are needed, it will probably be necessary to repeat Psu 10 and Psu 11 until both points are calibrated.

To change the hardware voltage limits, the power supply must be opened up and access obtained to the analogue pcb, CBJ1300. To adjust the negative limit, enter Psu 10 as described above and adjust RV2 to set the required limit. To adjust the positive limit, enter Psu 11 as described above and adjust RV3 to set the required limit.

Psu 12 automatically calibrates the measured lead current of the power supply. This test requires existing connections to the "magnet" and "switch heater" terminals to be removed. A link should then be connected between the two magnet terminals.

After entering Psu 12, the calibration is performed automatically but the display indicates something of what is happening:-

i)	Display measured current
ii)	Sweep to the +ve current limit and allow to settle
iii)	Sweep to the -ve current limit and allow to settle
iv)	A gain calculation is now performed
v)	Sweep to zero and allow to settle
vi)	Null measured current
vii)	Display measured current for 2 second
viii)	Exit to "Psu" menu.

This calibration should only be performed when the power supply is "warm", that is, when it has been running for at least 15 minutes.

Psu 14 automatically zeros the voltage and then the current measured by the power supply. This test requires existing connections to the "magnet" and "switch heater" terminals to be removed. A zero ohm link should then be connected between the two magnet terminals.

After entering Psu 14, the zeroing is performed automatically but the display indicates something of what is happening:-

i)	Display measured voltage for 2 second
ii)	Null measured voltage
iii)	Display measured voltage for 2 second
iv)	Display measured current for 2 second
v)	Null measured current
vi)	Display measured current for 2 second
vii)	Exit to "Psu" menu.

This calibration should only be performed when the power supply is "warm", that is, when it has been running for at least 15 minutes.

The error message "driFt Error" will be displayed if the output voltage drifts while zeroing. Ensure that the link is correctly placed.

8.5 Test 06, *Magnet System Configuration*

Configuration defines what type of magnet system the power supply will be a part of. On entry to test 6, a number in the range 0 to 255 is displayed, this represents "configuration" and may be adjusted by pressing LOC/REM and using RAISE and LOWER, releasing LOC/REM returns to the test menu. The displayed, decimal, number represents an 8-bit binary number, where the bits have the following significance (Bit 0 is LSB):

Bit 0	Superconducting switch fitted.
Bit 1	Reduced communications protocol (mimic PS126).
Bit 2	Aerosonics, VSM system.
Bit 3	Unipolar version of the power supply.
Bit 4	20 volt version of the power supply.

Bits 1 and 2 of "configuration" have a similar function to Bit 4, 5 & 6 of the serial link "Q" command, only they are non-volatile. Corresponding values are:-

Configuration	Q Command
0 (or 1)	Q0 (or Q2)
2 (or 3)	Q16 (or Q18)
4 (or 5)	Q48 (or Q50)
6 (or 7)	Q80 (or Q82)

Bit 3. Note that if a PS180-20 is configured as unipolar at the factory, then orange, yellow, violet and grey wires are disconnected from the reverse contactor coils, ensuring that the power supply can not possibly provide negative current.

The following are the most commonly required configurations:

16	PS180-20 No switch fitted
17	PS180-20 Switch fitted

8.6 Test 07, SUP(erconducting magnet) Menu

The "Sup" menu provides access to a set of operations designed to be carried out when initially setting up a magnet system. The majority will not be needed thereafter unless hardware changes are made.

"Sup" is entered from test 7 in the Test Menu, resulting in "Sup" being briefly displayed followed by "S" and an integer. RAISE and LOWER may be used to step through the menu and LOC/REM used to choose an option.

The table which follows lists the available options.

S 00	RETURN TO TEST MENU
S 01	DEFINE AMPS/TESLA
S 02	DEFINE POWER SUPPLY CURRENT LIMIT
S 03	DEFINE LOWER (MOST NEGATIVE) SAFE CURRENT
S 04	DEFINE UPPER (MOST POSITIVE) SAFE CURRENT
S 05	DEFINE CURRENT BREAKPOINTS FOR RATE LIMITING
S 06	DEFINE LIMITING RATE FOR LEADS, MAGNET AT ZERO
S 07	DEFINE LIMITING RATE FOR LEADS, MAGNET AT FIELD
S 08	DEFINE LIMITING RATE FOR MAGNET, "FAST" RUN
S 09	DEFINE LIMITING RATE FOR MAGNET, "TRAIN" RUN
S 10	NOT USED
S 11	NOT USED
S 12	NOT USED
S 13	NOT USED
S 14	NOT USED
S 15	SOFTWARE VOLTAGE LIMIT

Sup 01 defines a linear constant relating current and field. On entry, the maximum available current is displayed and may be adjusted by depressing LOC/REM and using RAISE and LOWER. Releasing LOC/REM causes an equivalent field to be displayed, which again can be adjusted. Initially, RAISE and LOWER may be used to shift the decimal point to the required position, then press LOC/REM and use RAISE and LOWER to set the number required. For accuracy, the "amps" and "tesla" entered should be large, convenient numbers.

The error messages "rAtE Error" or "dPt Error" will be displayed if some of the numbers entered are too large for the internal registers. If this should happen reduce the numerical values or change the position of the decimal point for the field display.

Sup 02 defines the power supply current limit. On entry the present limit is displayed and may be adjusted by depressing LOC/REM and using RAISE and LOWER. It will not be possible to set a SET POINT current greater than this limit.

Sup 03 and Sup 04 define a range of "safe power supply output currents.

Sup 03   defines the lowest or most negative "safe" power supply current.
Sup 04   defines the highest or most positive "safe" power supply current.

On entry the present safe current limit is displayed and may be adjusted by depressing LOC/REM and using RAISE and LOWER. If the two current limits are set to overlap then the error message "LAP Error" will be displayed.

If the measured current is outside these limits, the safe current output signal will not be given, see section 3 "Auxiliary Port Connections".

Sup 05 defines the current breakpoints marking the end of each maximum rate of change segment. Sup 5 should be used in conjunction with Sup 6,7,8 and 9; "b n" marks in the breakpoint (b) table the transition from rate r=n to r=n+1.

On entry, "b 00" is displayed, select a particular breakpoint from 0 to 15 using RAISE and LOWER, then press and release LOC/REM to display this breakpoint current, depressing LOC/REM a second time allows the user to adjust the selected current with RAISE and LOWER, releasing LOC/REM returns to the "b" menu.

"b 00" is fixed at 0 amps and "b 15" is fixed at full output current, pressing LOC/REM whilst either of these breakpoints are displayed will cause a return to the "Sup" menu.

Sup 06, Sup 07, Sup 08 and Sup 09 define the maximum rate of change of current in amps/minute for each maximum rate segment as defined in Sup 5. Each of the four Sup options set limiting rates for particular conditions:

Sup 06   for when the magnet system has a superconducting switch fitted, and the magnet is persistent at zero field.

Sup 07   for when the magnet system has a superconducting switch fitted, and the magnet is persistent at a non-zero field.

Sup 08   for running current into a normal, trained, magnet. Sup 8 defines the rates observed when "FAST" magnet sweep rate limits are selected.

Sup 09 for running current into a magnet that requires "training" after having been warmed. Sup 9 defines the rates observed when "TRAIN" magnet sweep rates are selected.

Each record "r n" in the rate (r) table sets the maximum rate of change between breakpoints b=n-1 and b=n.

On entry, "r 00" is displayed, RAISE and LOWER may be used to step to a particular segment from 0 to 15, press and release LOC/REM to display this maximum rate of change in amps/minute, depressing LOC/REM a second time allows the user to adjust the selected rate with RAISE and LOWER to a maximum value of 300.01 amps/minute, releasing LOC/REM returns to the "r" menu.

Pressing LOC/REM whilst "r 00" is displayed will cause a return to the "Sup" menu.

Sup 15 defines the characteristics of the software voltage limits. These limits are usually inhibited and are primarily intended to be used to protect magnets at the end of long or very resistive leads. Two parameters can be set, the voltage at which limiting should occur and the period for which the limit must be exceeded before any limiting action is taken.

On entry, the software voltage limit is displayed and may be adjusted by depressing LOC/REM and using RAISE and LOWER. Positive and negative voltage limits are set to the same value. By continuously monitoring the resistivity of the magnet system, the power supply is able to take into account the voltage drop along the current leads. Thus the software voltage limit should be set to just less than the voltage at which the magnet protection circuit would start to conduct.

When LOC/REM is released the display will read "SPELL" for a second then a time period, the "dwell spell", will be displayed. If the output voltage should continuously exceed the software voltage limit for this period, then the power supply will be tripped into a "catch" mode (see section 4.2). The dwell spell is defined in units of 1/4 second and can be adjusted by depressing LOC/REM and using RAISE AND LOWER. Dwell spell can be set to any value between 2 and 254 inclusive (between 1/2 second and about 1 minute), trying to set the dwell spell to < 2 will display the error message "2 Error". If the dwell spell is set to 255 (the maximum value) this function will be completely disabled.

The power supply is usually shipped with the software voltage limit set to 12.49 volts and the dwell spell set to 255 (inhibited).

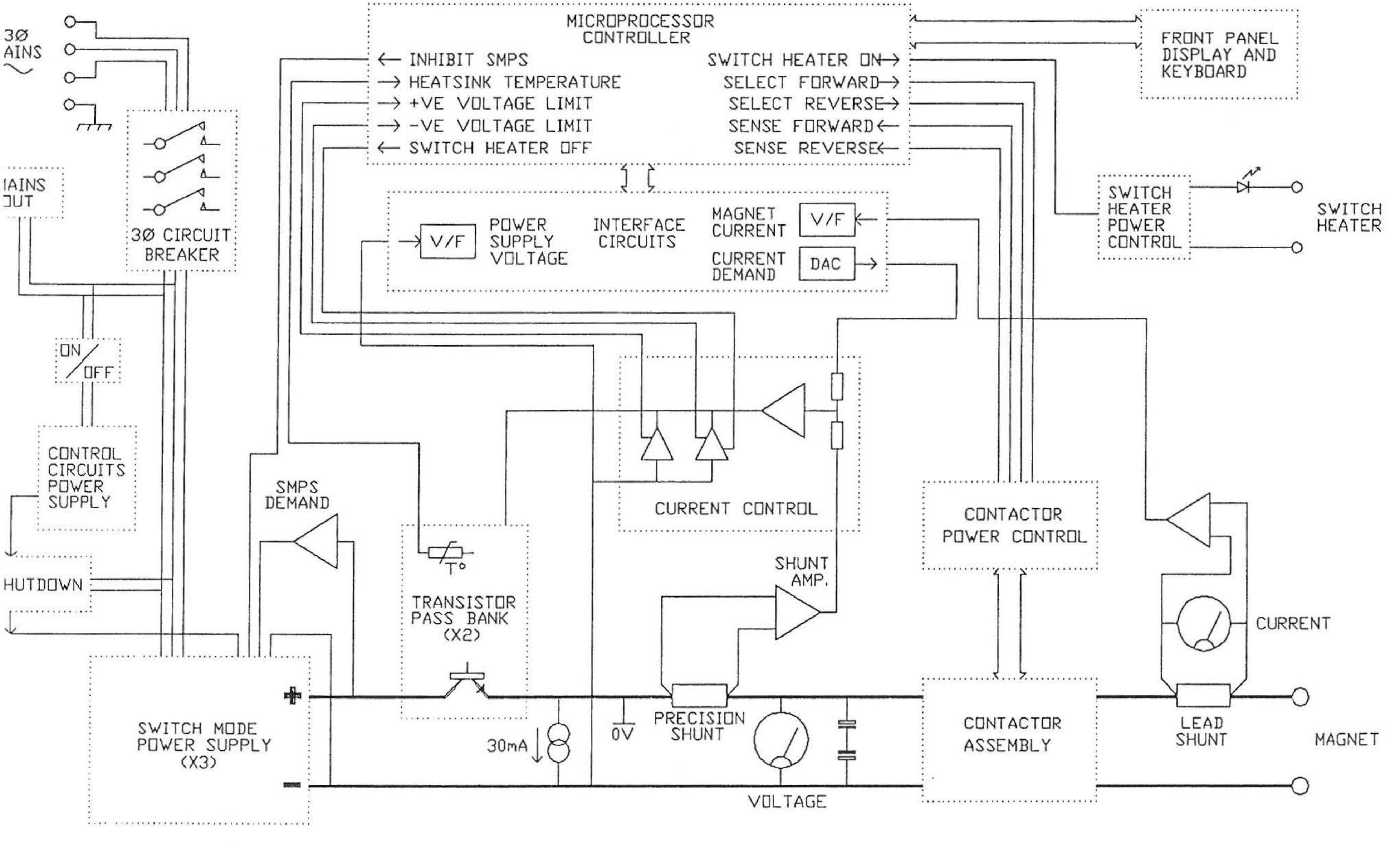
9 *SPECIFICATION*

OUTPUT CURRENT	0-180 Amps DC REVERSIBLE
CURRENT SETABILITY	0.01 Amp
CURRENT STABILITY	
STANDARD	18 mA per hour (100 ppm)
HIGH STABILITY	5 mA per hour (28 ppm)
CURRENT SWEEP	Digitally Generated
SWEEP RATE	0.01 Amp/min to 300 Amp/min in units of 0.01 Amp/min
STEP SIZE	2.75 mA approx.
VOLTAGE COMPLIANCE	+20 Volts to -20 Volts
CURRENT NOISE/RIPPLE	Less than 0.2% of FSD
CURRENT REVERSING	Integral, interlocked to prevent operation except at zero current.
SWITCH HEATER OUTPUT	0-100 mA into 100 Ohms
RS232 INTERFACE	Configured as DCE
HANDSHAKE	None Required
BAUD RATE	9600 Baud
IEEE-488 INTERFACE	Option, via external convertor.
CONNECTORS	
POWER IN	7 pin "AMP" type CPC series 3
CURRENT OUTPUT	Rear Panel Terminals
SWITCH HEATER OUTPUT	Rear Panel Terminals
RS232	25 way D socket
AMBIENT TEMPERATURE	0-40 degrees C.
COOLING	
STANDARD & HIGH STABILITY	Forced Air
HIGH STABILITY ONLY:	Water
TEMPERATURE STABILITY	+/- 1 deg C in 0 to 40 deg C range
CONSUMPTION	1 litre / minute
MAXIMUM PRESSURE	10 bar

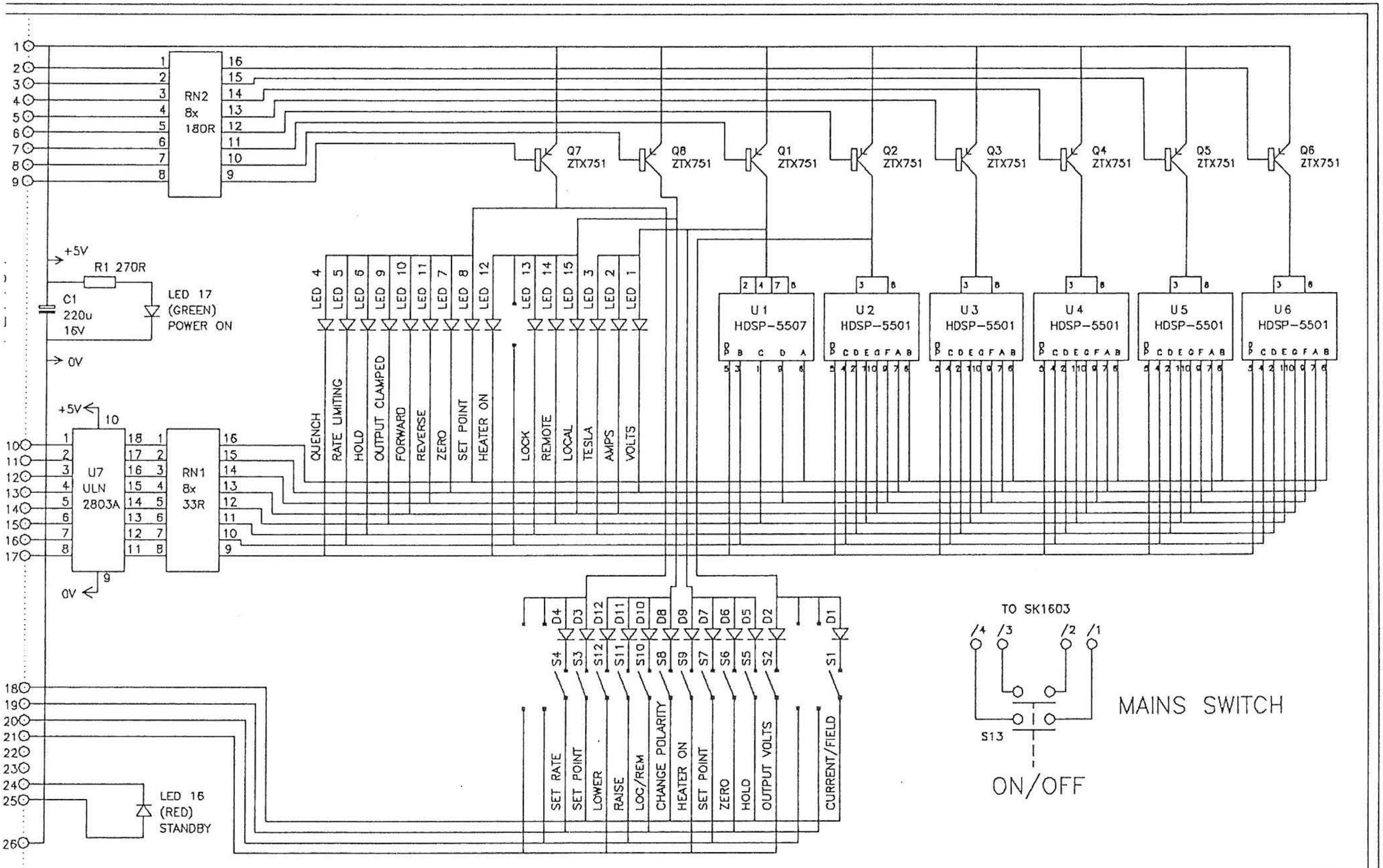
POWER REQUIREMENTS		
either THREE PHASE, DELTA	200-240 V 50/60 Hz	
or THREE PHASE, STAR	345-415 V 50/60 Hz	
POWER CONSUMPTION		
MAXIMUM	10 kVA	
DIMENSIONS		
FREE-STANDING	Height	446 mm
	Width	582 mm
	Depth	530 mm
RACK MOUNT	10U high	
WEIGHT	70 Kg	

10 CIRCUIT DIAGRAMS

CBJ0002	Block Diagram		
CBJ1102	Key/Display PCB		
CBD1202	(1)	Digital PCB	CPU, Memory and Timing
	(2)	Digital PCB	Input/Output Ports
CBJ1302	(1)	Analogue PCB	Current Control
	(2)	Analogue PCB	Analogue/Digital Interface
	(3)	Analogue PCB	Power Control
CBJ1402	Pass Bank PCB		
CBJ1602	(1)	Mains PCB and Wiring	High Power
	(2)	Mains PCB and Wiring	Low Power
CBJ2100	Front Panel Assembly		
CBJ2902	(1)	Wiring Loom	Upper Unit
	(2)	Wiring Loom	Lower Unit
	(3)	Wiring Loom	Contactor Control



		PS180-20 POWER SUPPLY BLOCK DIAGRAM	OXFORD
			DRAWING NUMBER A4/ CBJ0002
19/11/92			

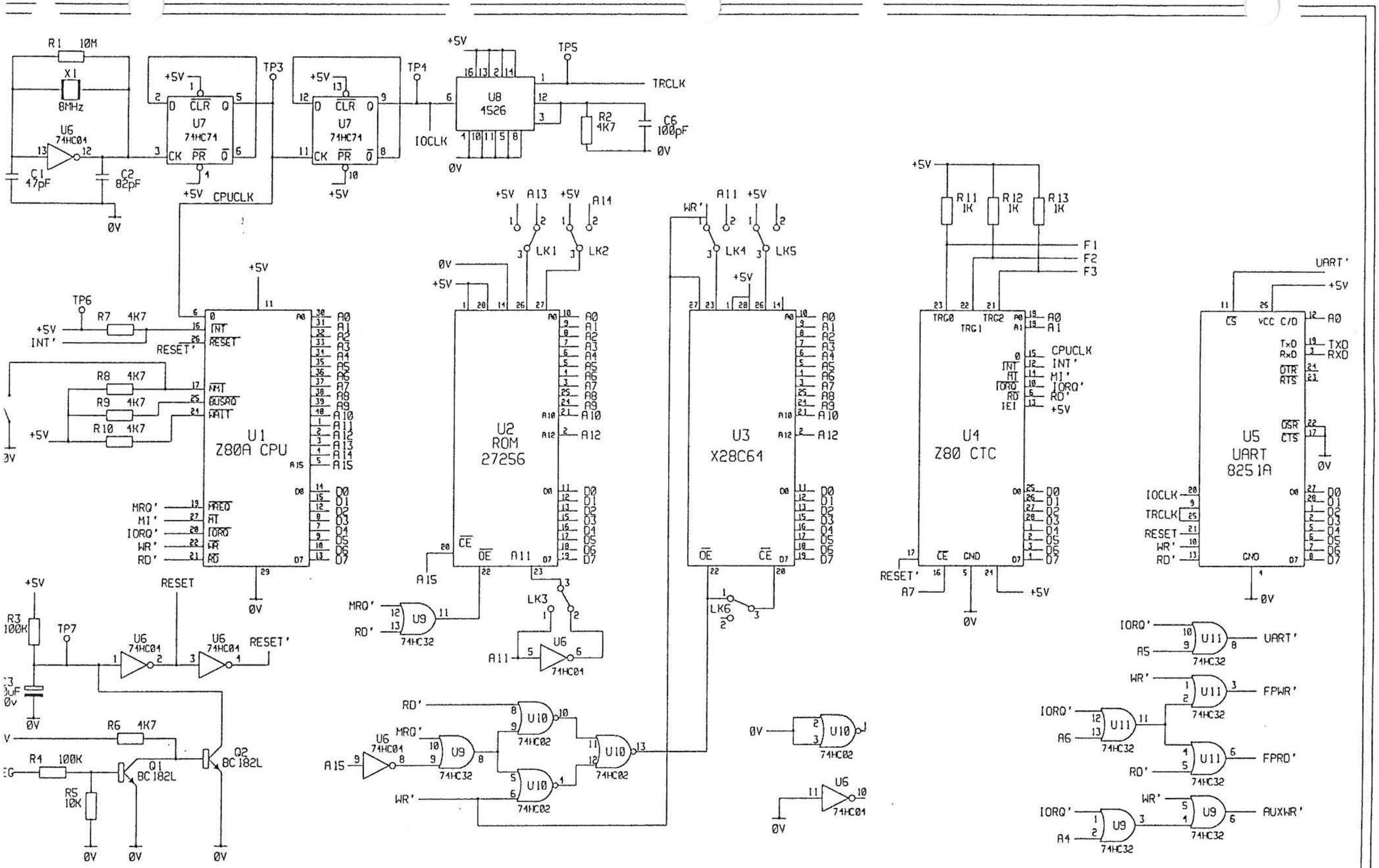


24/5/89

PS180-20 POWER SUPPLY
KEY/DISPLAY PCB

OXFORD

DRAWING NUMBER
A4/ CBJ1102

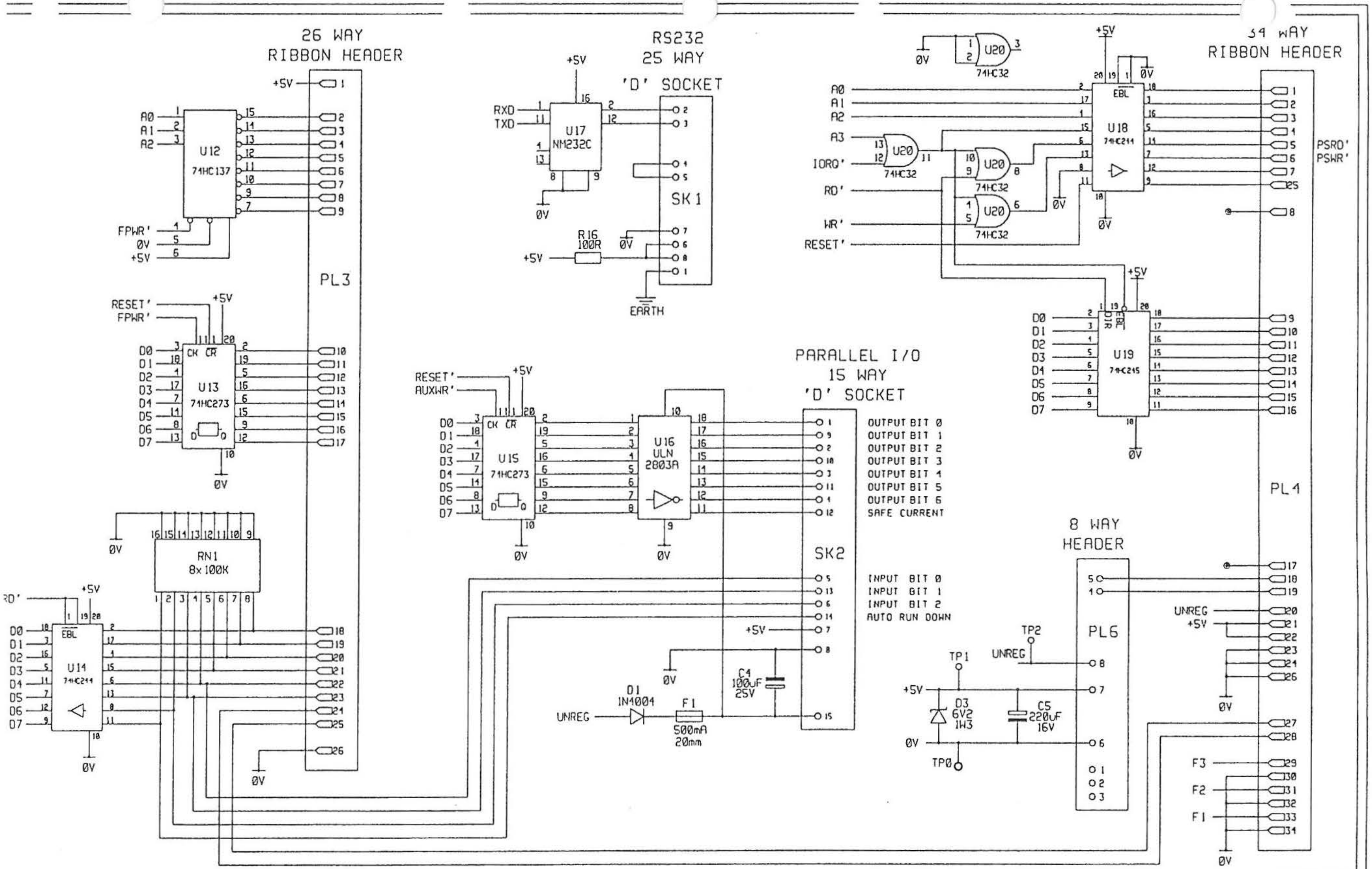


TITLE MAGNET POWER SUPPLY
DIGITAL PCB
CPU, MEMORY AND TIMING

OXFORD

DRAWING NUMBER A4 CBD 1202 1 of 3

15/11/93

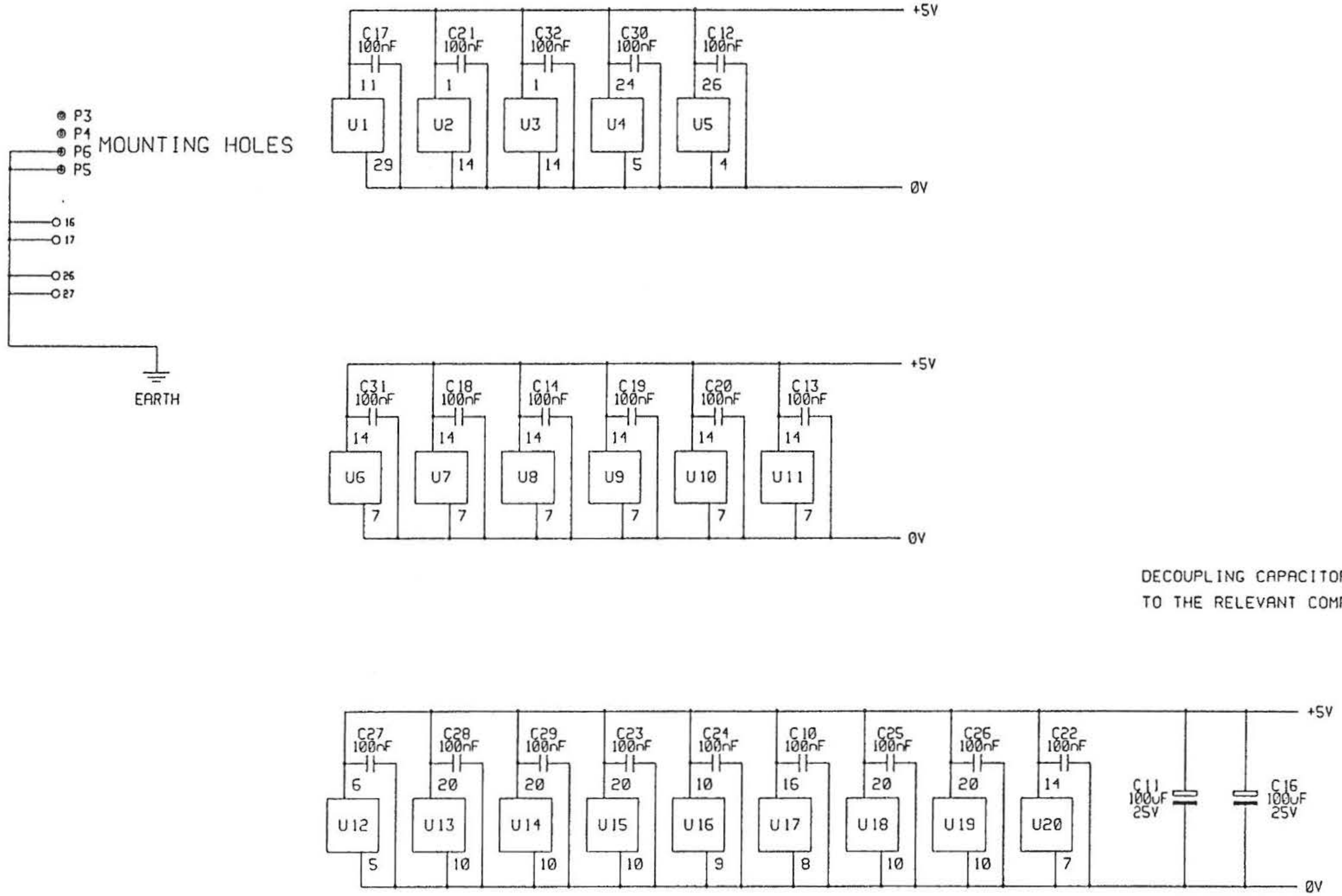


15/11/93	

TITLE MAGNET POWER SUPPLY
DIGITAL PCB
INPUT / OUTPUT PORTS.

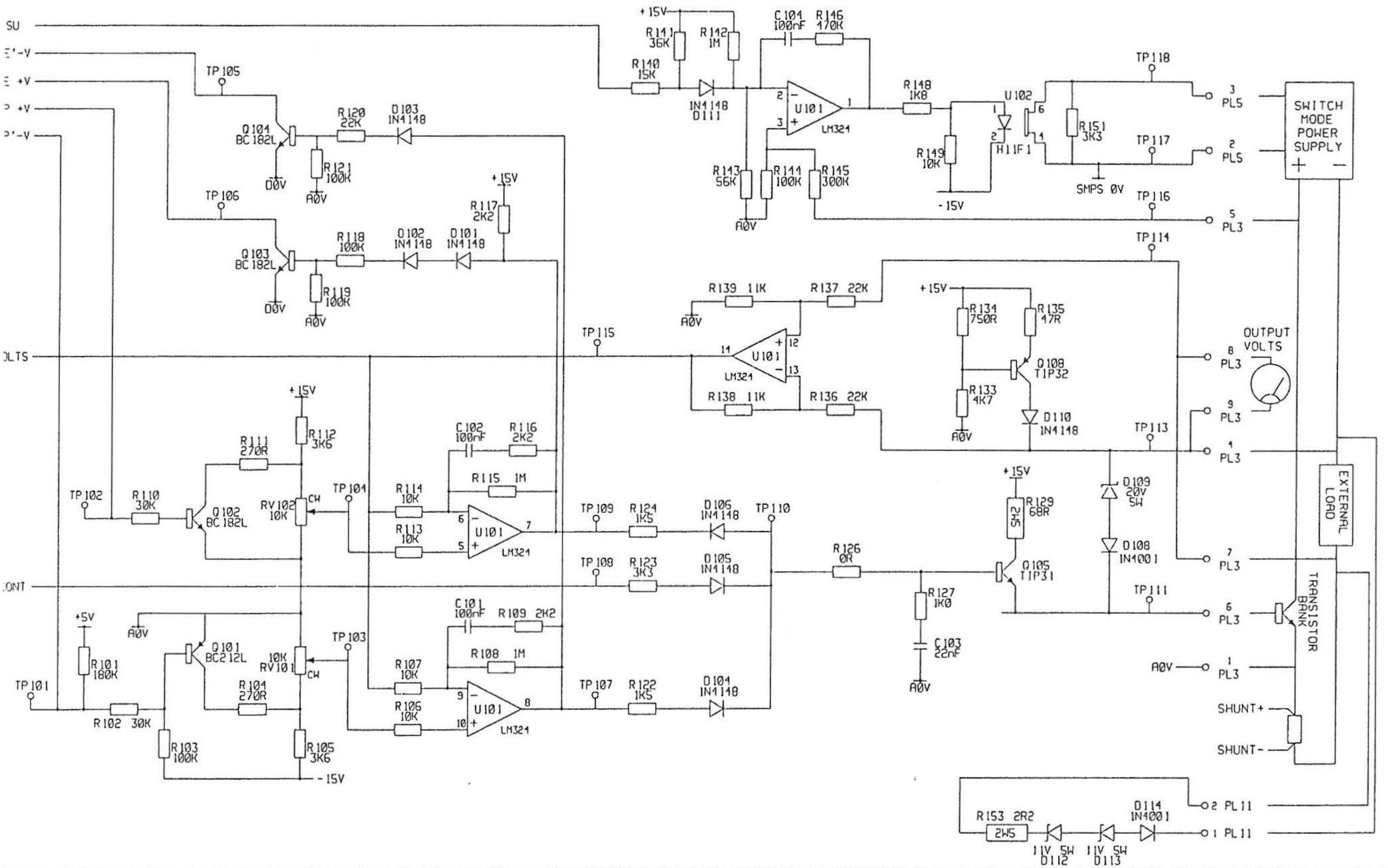
OXFORD

DRAWING NUMBER
A4 CBD 1202 2 of 3



DECOUPLING CAPACITORS TO BE CLOSE
TO THE RELEVANT COMPONENT.

		TITLE	
		MAGNET POWER SUPPLY	OXFORD
		DIGITAL PCB	DRAWING NUMBER
15/11/93		DE-COUPLING CAPACITORS etc.	A4 CBD 1202 3 of 3



5/10/93	NEGATIVE LOGIC IS INDICATED BY '

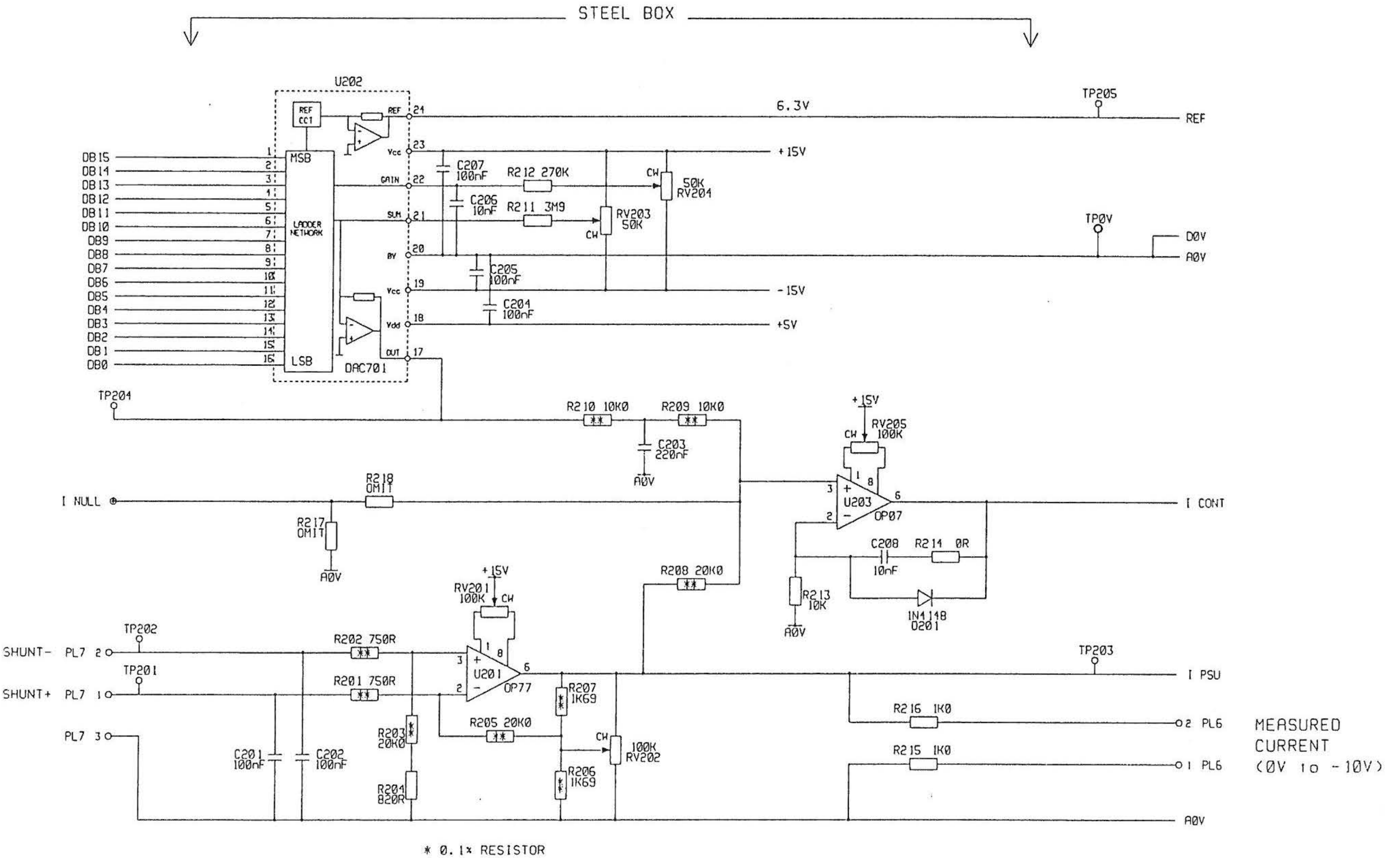
TITLE

PS180-20 POWER SUPPLY
ANALOGUE PCB
OUTPUT CONTROL

OXFORD

DRAWING NUMBER

A4 CBJ1302 1of5



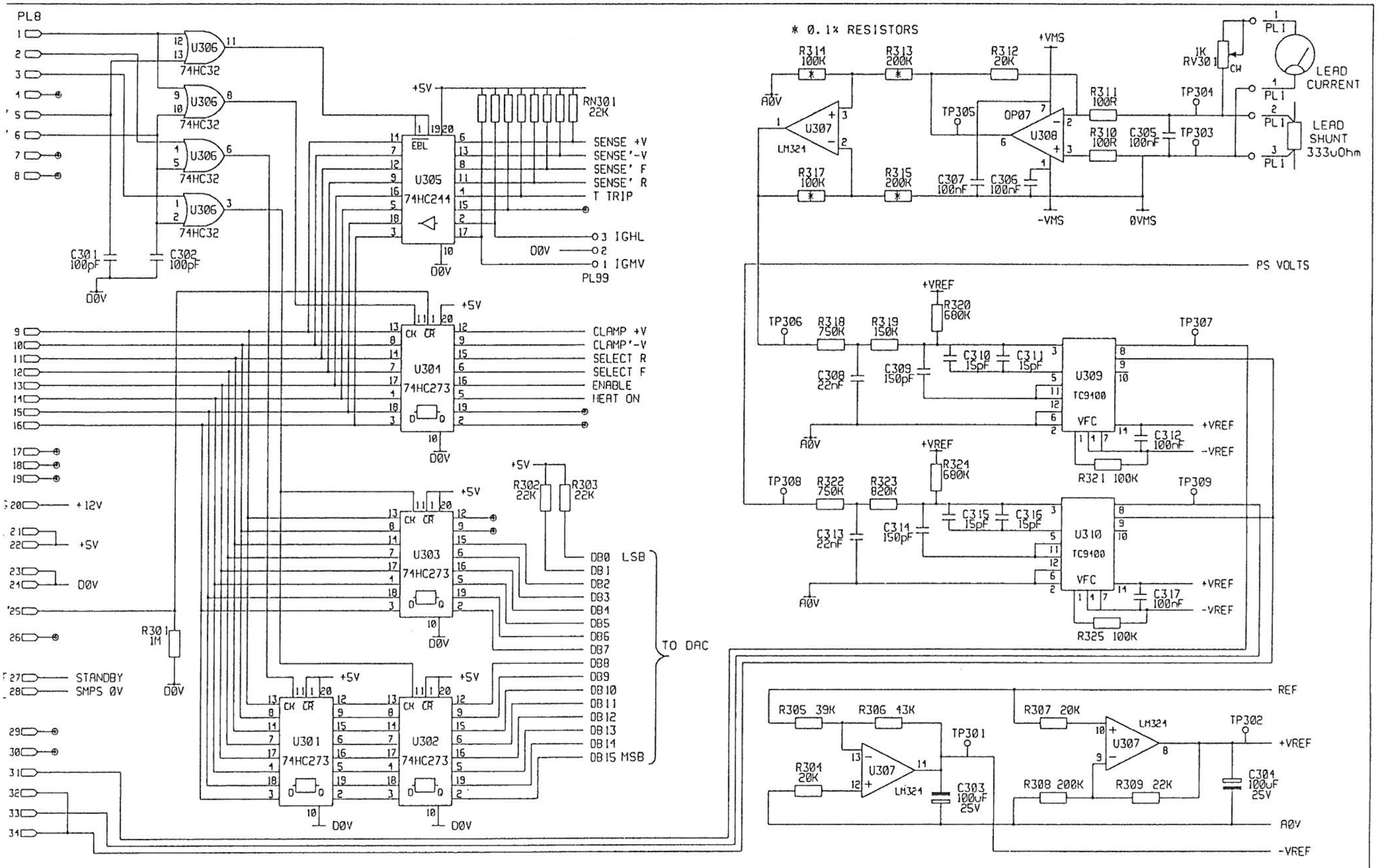
5/10/93	NEGATIVE LOGIC IS INDICATED BY '

TITLE

PS180-20 POWER SUPPLY
ANALOGUE PCB
CURRENT CONTROL

OXFORD

DRAWING NUMBER
A4 CBJ 1302 2of5



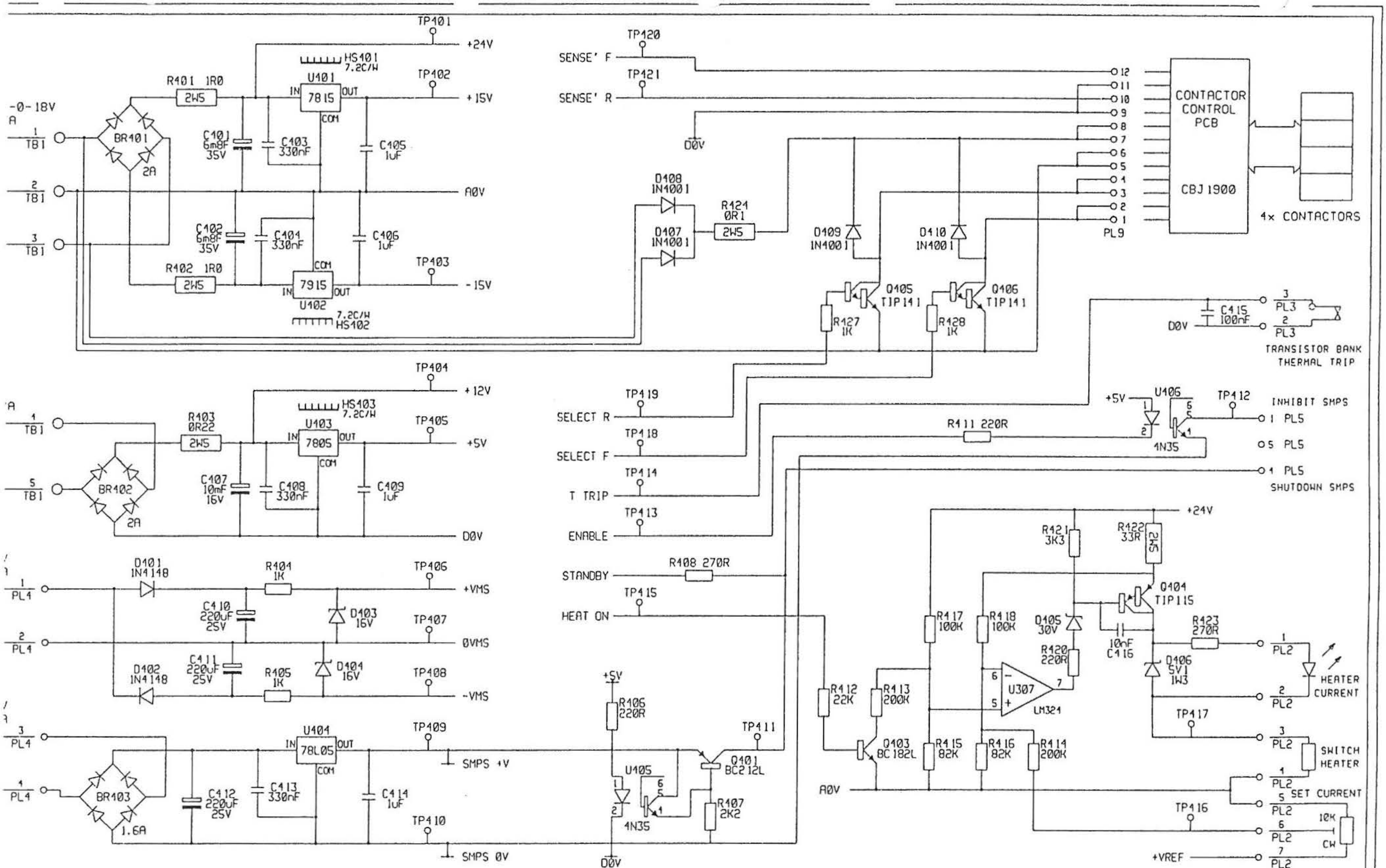
5/10/93	NEGATIVE LOGIC IS INDICATED BY '

TITLE

PS180-20 POWER SUPPLY
ANALOGUE PCB
ANALOGUE/DIGITAL INTERFACE

OXFORD

DRAWING NUMBER
A4 CBJ1302 3of5



5/10/93	NEGATIVE LOGIC IS INDICATED BY '

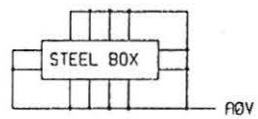
TITLE

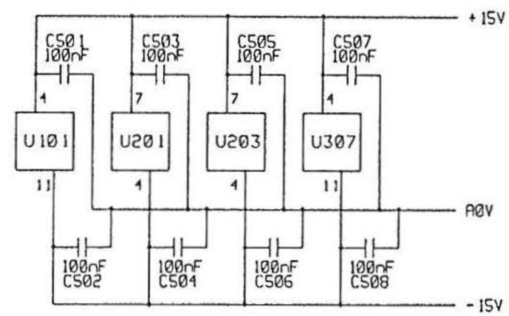
PS180-20 POWER SUPPLY ANALOGUE PCB POWER CONTROL

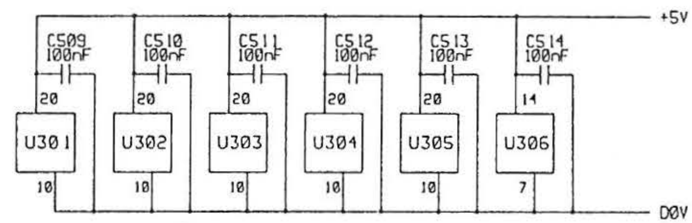
OXFORD

DRAWING NUMBER

A4 CBJ1302 4of5







5/10/93	NEGATIVE LOGIC IS INDICATED BY '

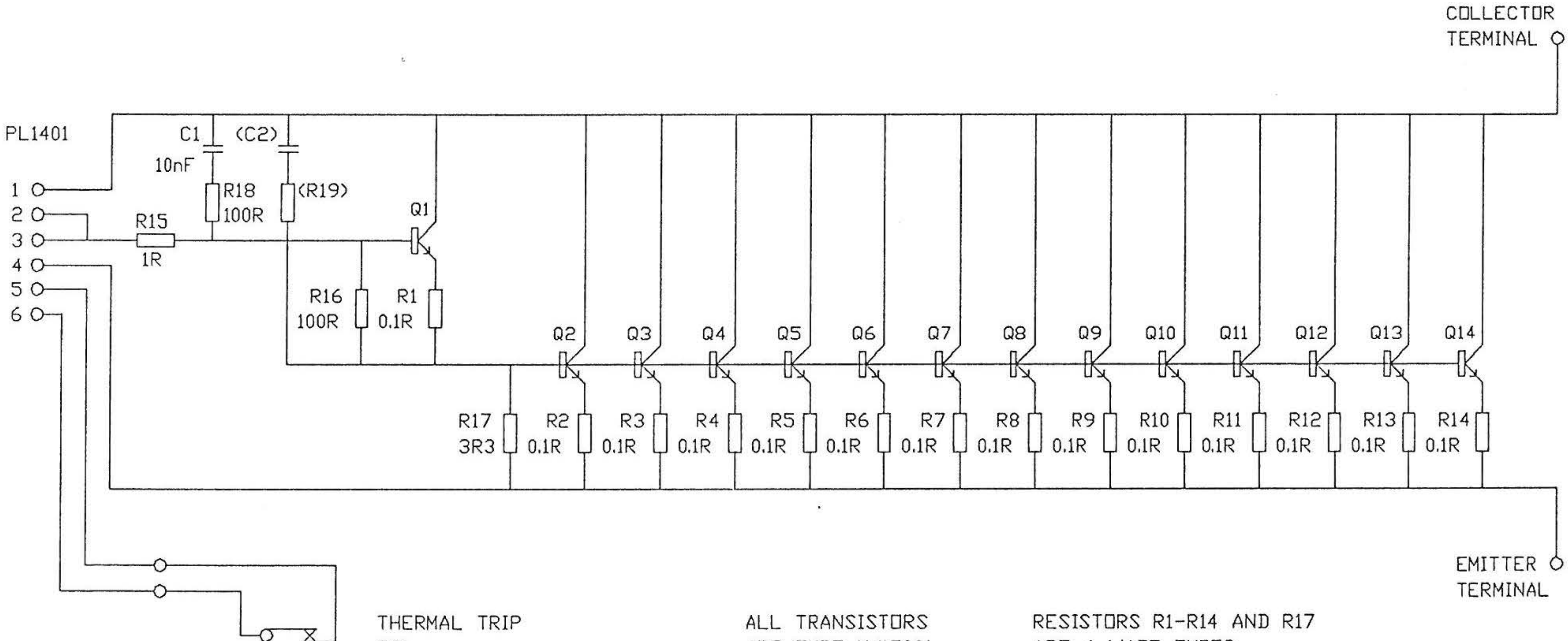
TITLE

PS180-20 POWER SUPPLY
ANALOGUE PCB
DE-COUPLING CAPACITORS etc

OXFORD

DRAWING NUMBER

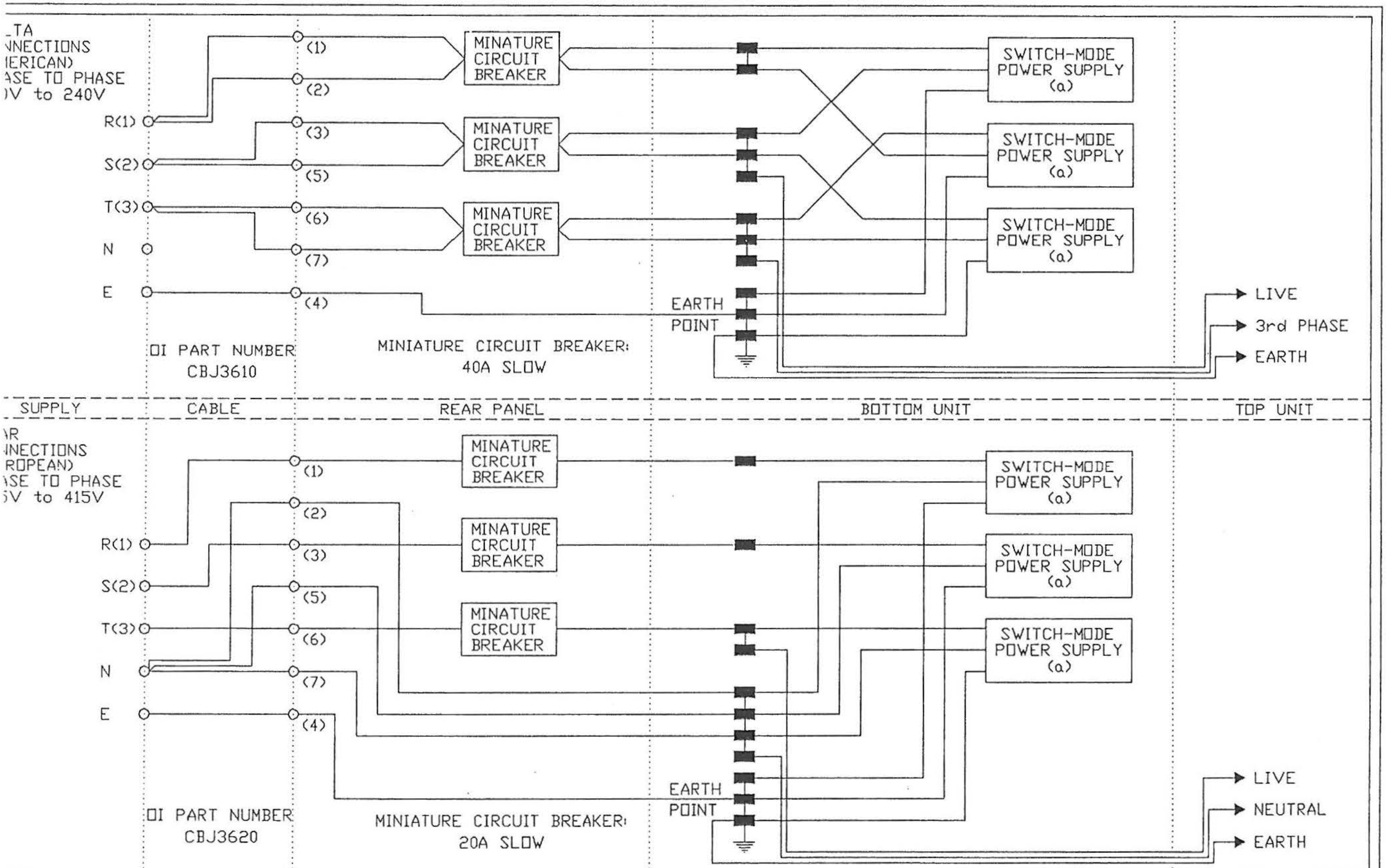
A4 CBJ1302 5of5



ALL TRANSISTORS
ARE TYPE MJ15001

RESISTORS R1-R14 AND R17
ARE 4 WATT TYPES

20/11/92		PS180-20 POWER SUPPLY PASS BANK PCB	OXFORD DRAWING NUMBER A4/CBJ1402

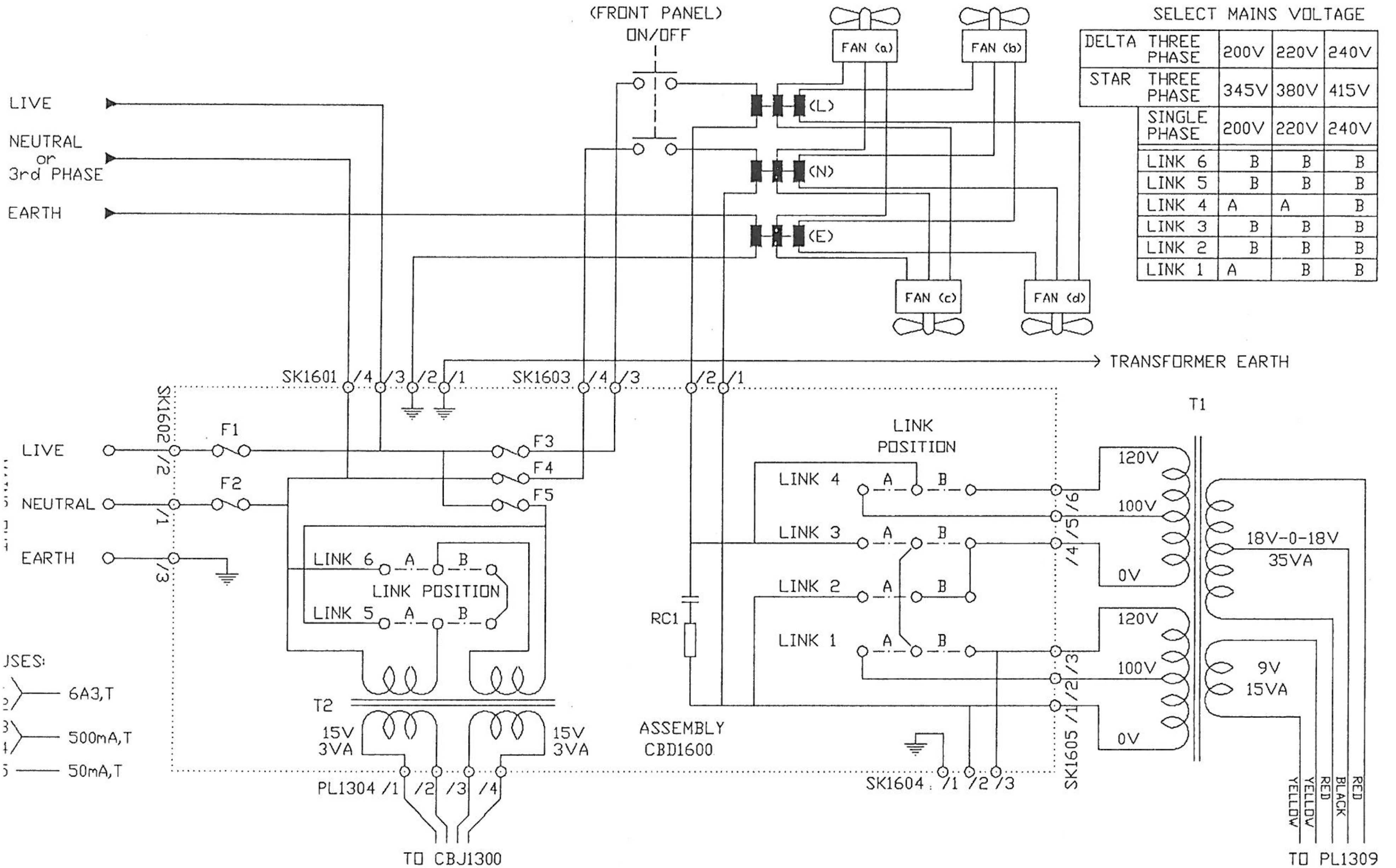


J	9/3/93	

PS180-20 POWER SUPPLY
MAINS WIRING
HIGH POWER (THREE PHASE)

OXFORD

DRAWING NUMBER
A4/ CBJ1602 1of2



SELECT MAINS VOLTAGE

DELTA THREE PHASE	200V	220V	240V
STAR THREE PHASE	345V	380V	415V
SINGLE PHASE	200V	220V	240V
LINK 6	B	B	B
LINK 5	B	B	B
LINK 4	A	A	B
LINK 3	B	B	B
LINK 2	B	B	B
LINK 1	A	B	B

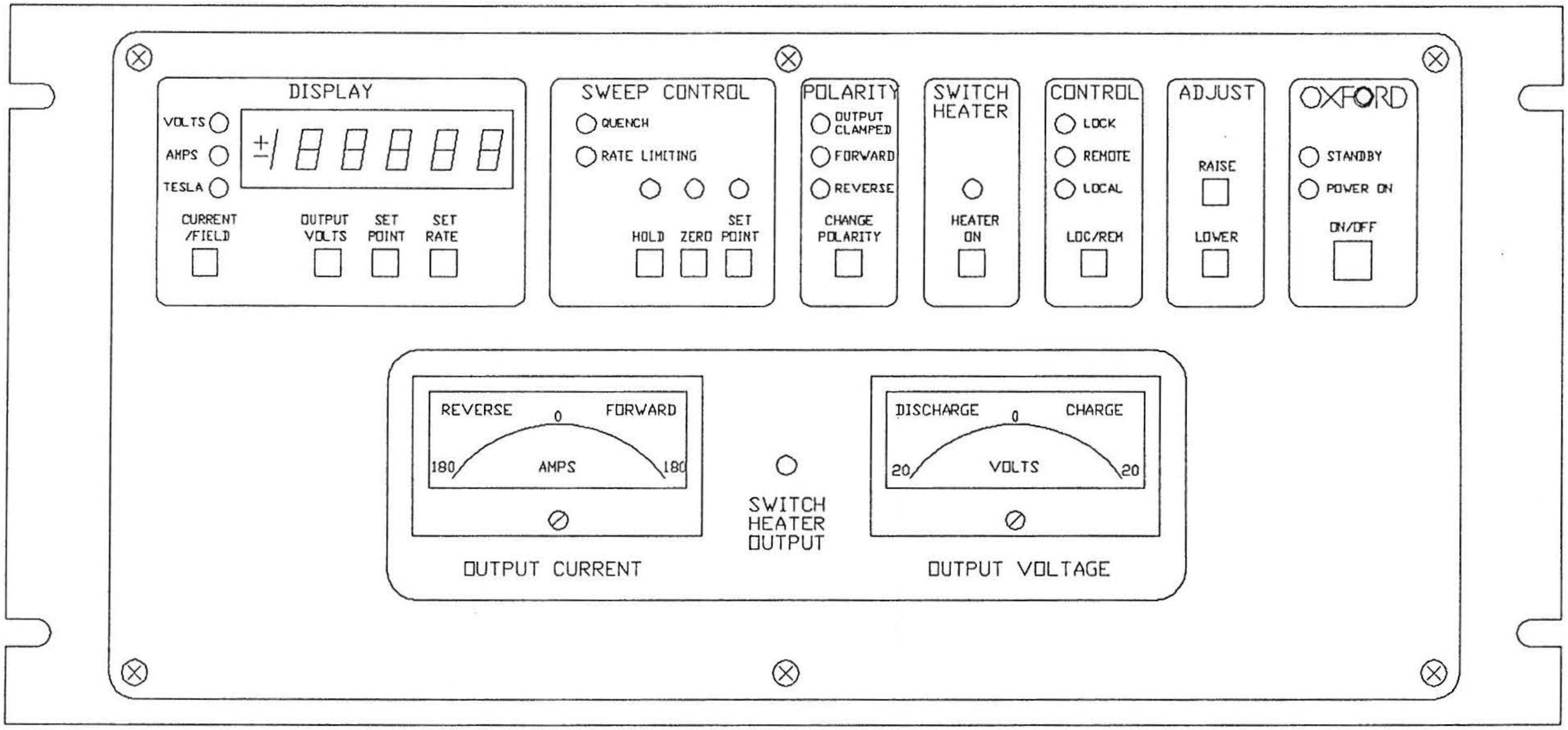
J | 9/3/93 | COMPONENTS SHOWN OUTSIDE THE DOTTED LINE ,·········· ARE NOT ON CBD1600.

PS180-20 POWER SUPPLY
MAINS WIRING
LOW POWER (SINGLE PHASE)

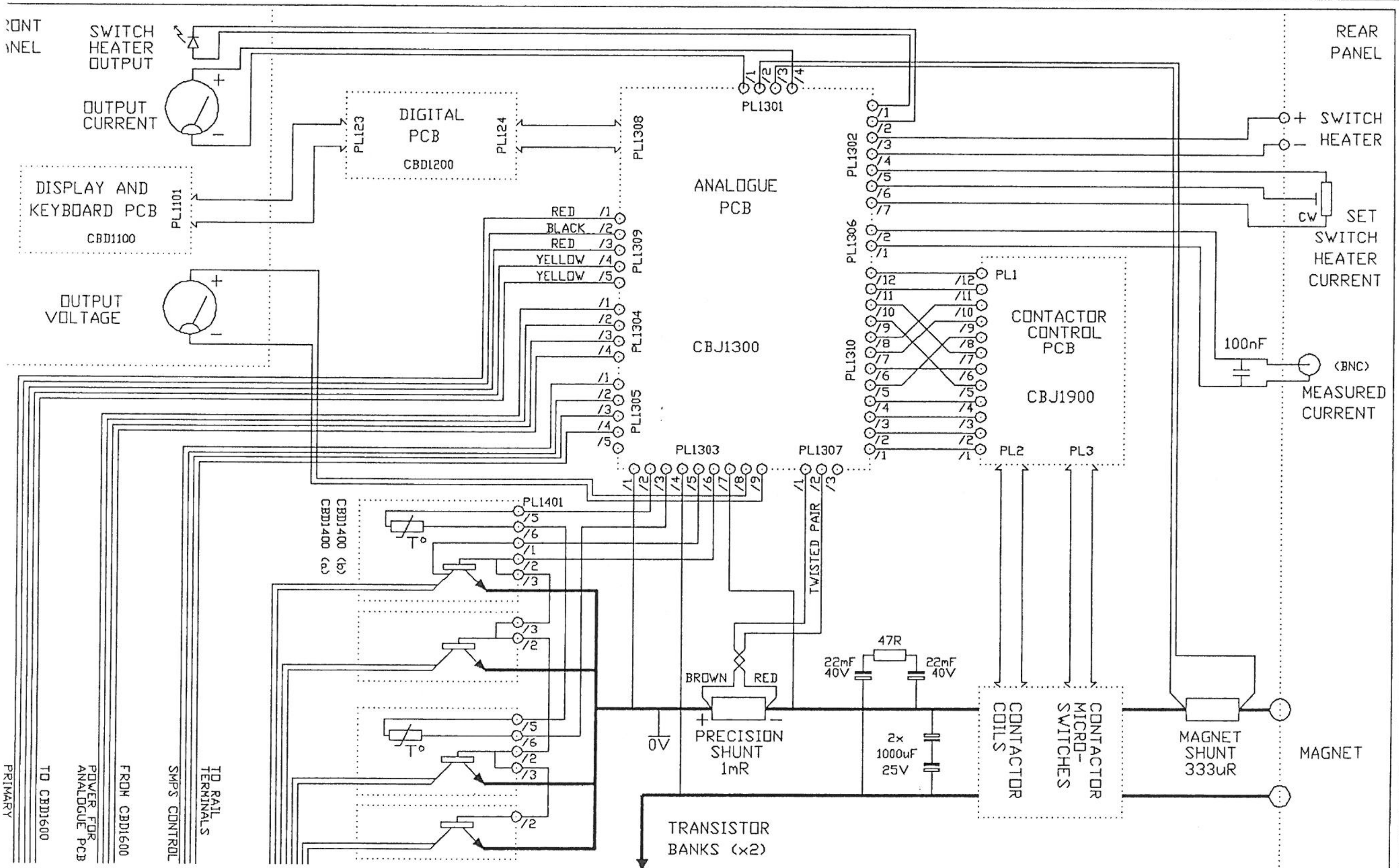
OXFORD

DRAWING NUMBER

A4/ CBJ1602 2of2



20/11/92	SCALE 1:2	PS180-20 POWER SUPPLY FRONT PANEL ASSEMBLY	OXFORD DRAWING NUMBER A4/ CBJ2100

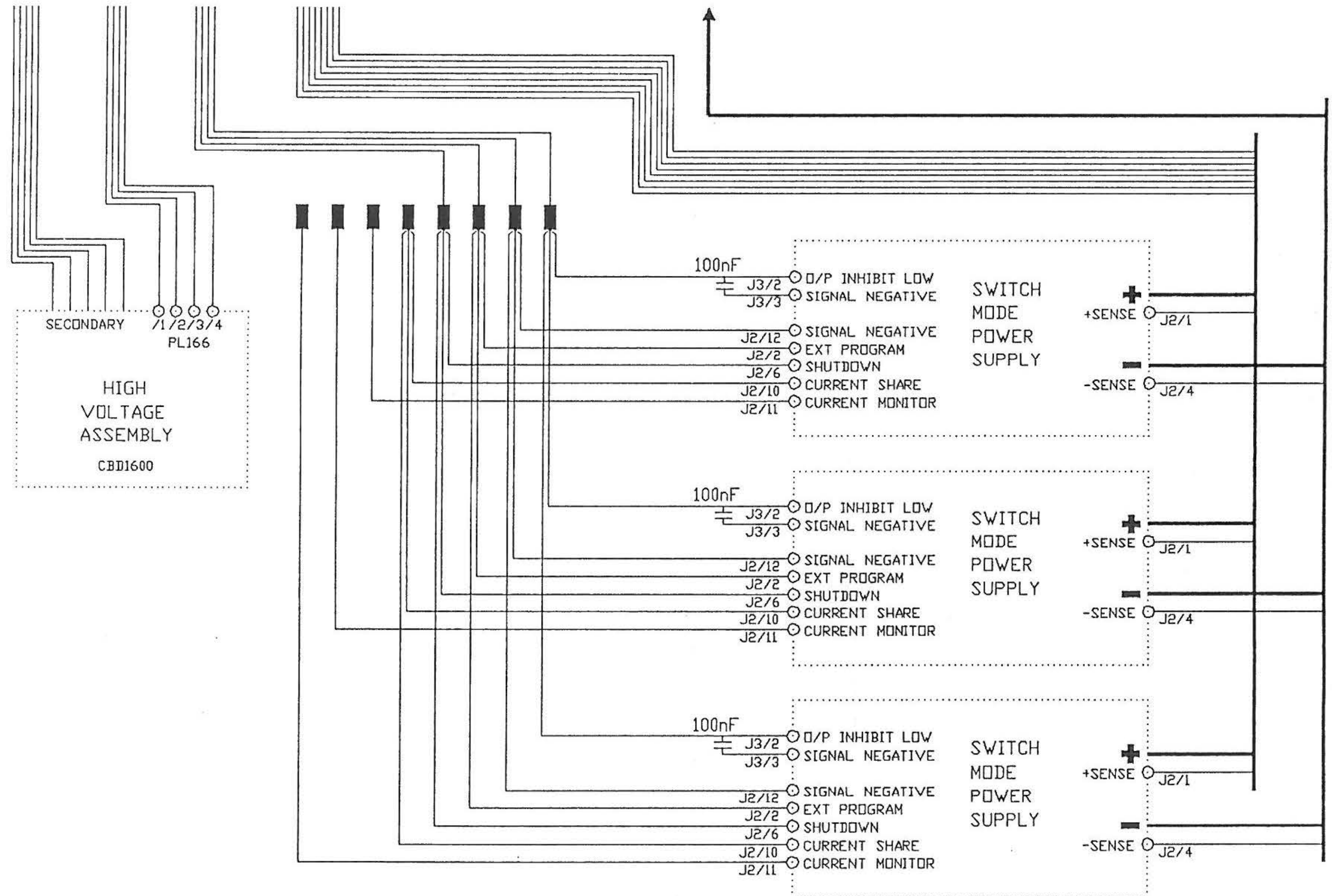


J	9/3/93

PS180-20 POWER SUPPLY
WIRING LOOM
UPPER UNIT

OXFORD

DRAWING NUMBER
A4/ CBJ2902 1of3



J	9/3/93	

PS180-20 POWER SUPPLY
WIRING LOOM
LOWER UNIT

OXFORD

DRAWING NUMBER
A4/ CBJ2902 2of3